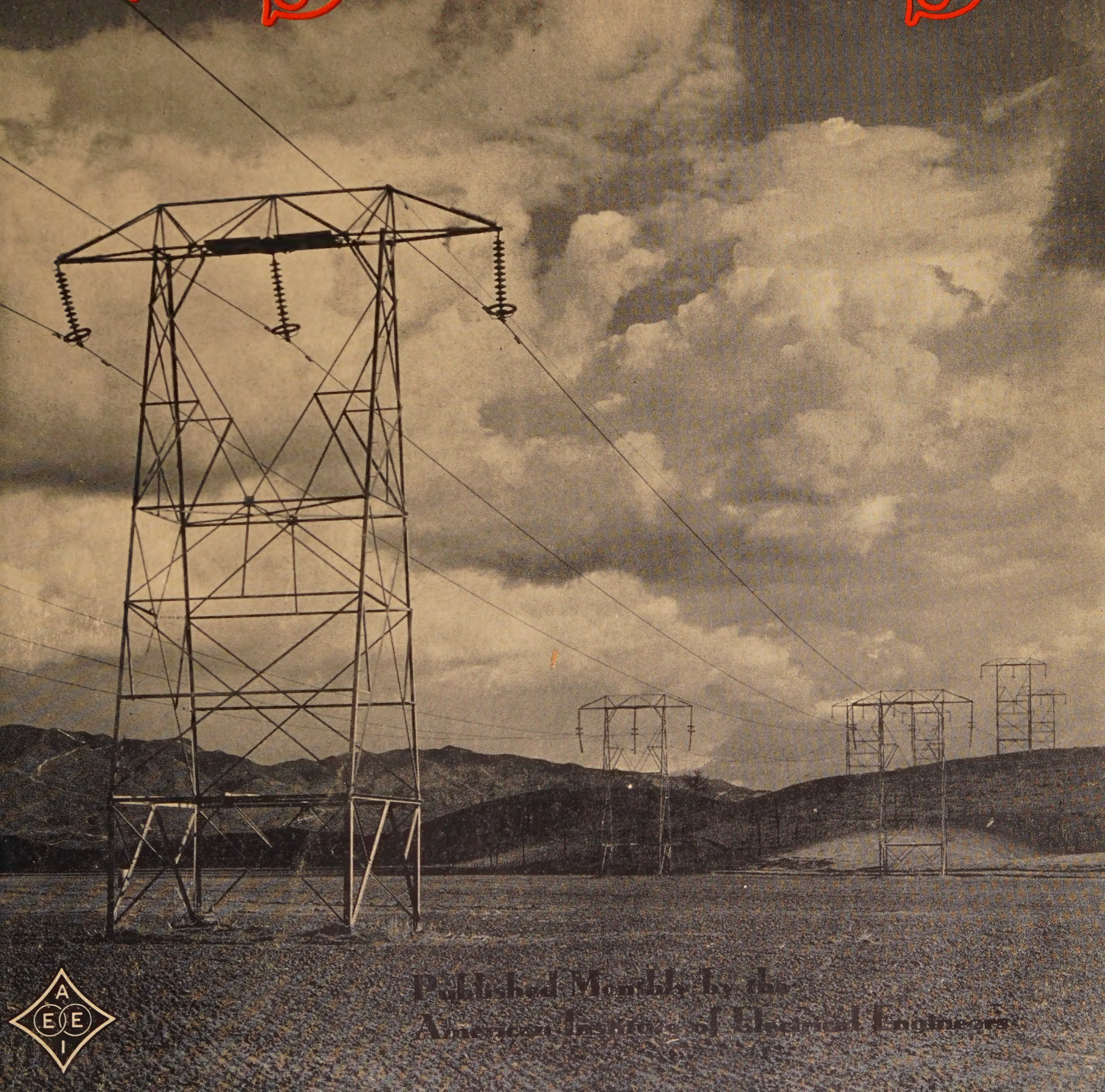
Electrical Engineering

August
1937



Published Monthly by the
American Institute of Electrical Engineers

AUTOMATIC **NEWS** SWITCHING

Switchgear Headquarters

Attended Stations Now Use Automatics

Railroad Praises Automatics After Unusual Test

One of the outstanding western railroads, which is operating 14 automatic substations on one division, reports that, although its automatic switching equipment performed 4445 operations during one month this year, there was not a single service interruption during that time.

On the average, each automatic substation started and shut down automatically 10 times each day, and during this period only routine service visits were made to the substations by maintenance men.

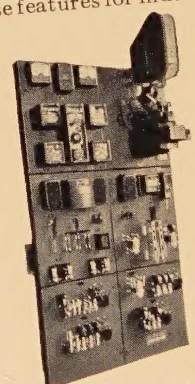
This road's first automatic equipment was a 300-kw synchronous converter with full automatic control, purchased back in 1919. Since then, numerous additions to the system, including a 500-kw mercury arc rectifier with full automatic control, have been made.

Moving Trains in Manhattan

Automatics are an important factor in the continuous power supply for the subway trains in New York City. Here is G-E equipment in one of the unattended stations of the city's Independent Subway System.

Build Automatic Switching Equipment for Industrials

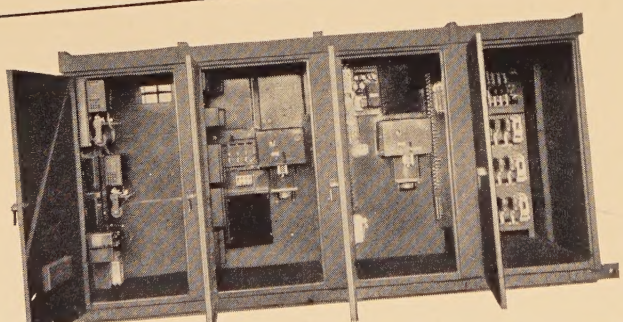
For some time the advantages of automatic switchgear with the automatic reclosing features for mercury arc rectifiers have been recognized in railway service. The value of these features for industrial



rectifiers, even in attended substations, is now obtaining increased recognition.

The equipment illustrated is typical of an automatic installation of this kind for an industrial process for which the d-c voltage control over a range of 474 to 537 volts is obtained by rectifier grid control. The a-c and d-c breakers reclose automatically a desired number of times in case of faults.

Open for Inspection



Here is a unique automatic synchronous-condenser installation. It operates over a range of a-c voltage from 65 to 110 per cent, with only a-c control power available for the operation of the control equipment and for closing the circuit breakers. It is a portable outdoor installation and is representative of the more exacting requirements which present-day automatic installations must meet.

More Reliability Being Regarded Essential Feature

Although the economies obtained in operating an unattended station provided the impetus for the development of automatic switchgear, today electric-service companies are finding that this reliable mechanism is an essential feature of their *attended* stations. The more accurate functioning of automatic starting, regulating, stopping, and protecting has brought about the change.

This is primarily due to the dependability of each device included in the equipment, plus the fact that control is automatic and the proper function is always performed at the proper time—and even under emergency conditions the equipment is not subject to possible incorrect operation and delay.

Install Automatic Load Control In New England

In New England an interesting installation has been made in which automatic load-control equipment in combination with an automatic hydroelectric generating equipment is used to limit to a predetermined value the power input from the power company's incoming line. This is done by making the generator take on any available load above the predetermined amount. Adjustment can easily be made in order to hold whatever value of power input is desired from the incoming line.

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.

GENERAL ELECTRIC

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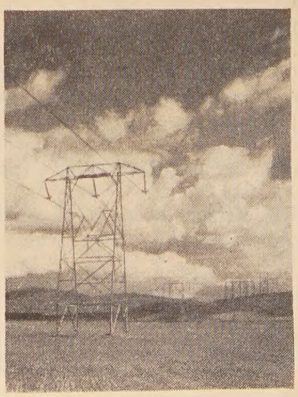
Electrical Engineering

Registered U. S. Patent Office

for August 1937—

The Cover

A 220-kv line of the Southern California Edison Company



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High Lights

The Engineer and Society. Two stimulating addresses on the general subject of the engineer and his relation to society were delivered at the Institute's 1937 summer convention in Milwaukee, Wis.; both of these addresses are published in this issue. The first address, on the subject of "The Engineer and His Relation to Government," stresses the need for a more effective expression of the engineer's viewpoint on important public questions (*pages 928–36*). The second address discusses the position and duties of "The Engineer in a Changing World" and emphasizes the necessity for engineers to exercise their responsibilities more for the sake of society as a whole than for the sake of themselves or the private interests of the businesses with which they may be connected (*pages 937–41*). In a third article on this same general subject, an electrical-engineering student urges engineers to "interest themselves in something outside their narrow technical field . . . and become human and humanitarian" (*pages 943–4*).

Circuit Breakers. Simply dividing a circuit breaker into several units will not raise its interrupting capacity as a multiple of the number of breaks, because the voltage distribution across the breaks is not uniform. Capacitance shields will give a satisfactory distribution of duty in multibreak circuit breakers (*pages 1018–24*). Ultrahigh-speed reclosing of oil circuit breakers is said to provide an effective and economical solution to the problem of reducing transmission-line outages and thereby improving continuity of service (*pages 968–70*).

Federal Power in the Northwest. The federal administration of a public utility is a new idea in the United States; consequently, the formulation of some ultimate plan of administration has become a problem of major importance. The Tennessee Valley Authority and the plans proposed for the public administration of power from the Bonneville and Grand Coulee projects have been compared with the Ontario Hydro-Electric Commission and the British Grid (*pages 964–7*).

Summer Convention Reports. Reports covering the various activities of the Institute's 1937 summer convention held in Milwaukee, Wis., June 21–25, are published in the news section of this issue. Included are reports of the annual business meeting, the presentation of the Lamme Medal, conference of officers, delegates, and members, 2 technical conferences, prepared discussions on Institute activities, board of directors meeting, and other features (*pages 1042–52*).

Radiotelephone Noise Reduction. Several conventional methods, such as the use of higher power, directive antennas, and selective filters, may be used to increase the intensity of the signal with respect to the noise level in transmitting speech over radiotelephone circuits. Another method, somewhat unconventional in character, consists of diminishing the noise during the intervals of no speech (*pages 971–4*).

Resonant Lines. Transmission lines, composed of either parallel or concentric wires, provide a stable means of frequency control for ultrahigh radio frequencies of 30 megacycles or more. Radiation resistance has been found of dominant importance in determining the selectivity factor and input impedance, and therefore materially changes the optimum design of the line (*pages 1002–11*).

Electricity on Aircraft. Applications of electricity in modern aircraft construction are manifold, because electrical operation is convenient and the equipment required is relatively light in weight. The electrical system of a modern transport ship is described in a paper in this issue (*pages 959–63*).

Power Inrushes Under Load. "Starting" currents in transformers have been studied by several investigators, but most of such tests have been conducted under the special condition of no load. A paper in this issue presents the results of a study of starting currents in transformers connected to loads having various power factors (*pages 989–94*).

Electric Range Units. Several types of surface heating units are used in electric ranges, the heat being transferred by radiation, conduction, or both. The efficiency of heat transfer varies with the type of unit, and may be improved, particularly for radiation, by the use of black-bottom utensils (*pages 953–8*).

Eta Kappa Nu Recognition. An honorary electrical-engineering society has established awards to recognize outstanding young electrical engineers; statistics for the nominees for the 1936 awards reveal significant information concerning the leading American engineers under 35 years of age (*pages 945–9*).

Cooling Transformers. Units composed of a radiator and fan, commonly used for heating industrial buildings, have been found suitable by an eastern power company for cooling transformers by circulating oil from the transformer through the unit. A water spray further increases its effectiveness (*pages 950–2*).

Pacific Coast Convention. Plans are nearing completion for the AIEE 1937 Pacific Coast convention to be held in Spokane, Wash., August 30–September 3. The Pacific Northwest offers splendid opportunities for combined vacation-convention trips (*page 1053*).

Harmonic Generation. A harmonic generator circuit, suitable for the supply of carrier currents to multichannel telephone systems, for synchronization of carrier frequencies in radio transmission, and for frequency comparison, has been developed (*pages 995–1001*).

Series Capacitors. Improved voltage regulation in power circuits may be obtained by the insertion of capacitors in series with the line. Sometimes, however, difficulties such as hunting of synchronous machines and self-excitation of induction motors arise which require investigation (*pages 975–88*).

The Vodas. Suppression of feedback and singing in the interconnection of ordinary telephone systems by means of radiotelephone links requires a special type of apparatus known as the "vodas" (*pages 1012–17*).

The Engineer of Tomorrow. Some thought-provoking questions were propounded by President MacCutcheon concerning the engineer of tomorrow, in his 1937 summer-convention address (*pages 941–3*).

New AIEE Officers. Nine officers were newly elected at the recent AIEE summer convention to serve the Institute during the ensuing year (*page 1049*).

DISCUSSIONS

Appearing in this issue are discussions of the following papers:

Electrical Machinery

Protective Devices

Tensor Analysis

Statements and opinions given in articles and papers appearing in Electrical Engineering are the expressions of contributors, for which the Institute assumes no responsibility. Correspondence is invited on all controversial matters. ¶ Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the fifteenth of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ Electrical Engineering is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London).

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A Message From the President

Fellow Members of the Institute:

I SHOULD LIKE to take this opportunity to say to all of you what I had the privilege of saying to those at the summer convention in Milwaukee in response to notification of election as president:

"Instinctively I feel sure you understand how wholly inadequate words of mine are to express appreciation of the great honor the membership of the Institute has conferred upon me.

"I am mindful of the responsibility that goes with the high and cherished office of president, and with humility I confidently look forward to this distinguished opportunity further to serve the profession in which we are spending our lives.

"It has been my privilege for many years to participate in the affairs of the Institute, and I am familiar with its high ideals, its traditions—its responsibilities to the profession at large.

"No period has ever afforded our organization a greater opportunity to be of service.

"One need but recall the many new developments looming on the horizon in almost every phase of the industry to visualize the important part the Institute will play in the period ahead. Perhaps even more immediate and bearing on the profession as a whole is the situation presented by the changing social and economic order of the world in which we live. In this we as engineers face a stiff challenge—a broadened horizon. The engineering societies can do much to point the way.

"The joy and satisfaction one gets in service to the Institute is the opportunity afforded for associations and acquaintanceships with the membership, and I am eagerly looking forward to this through the coming year.

"The life of the Institute is in the Districts, Sections, Student Branches, and committee activities. No organization, year in and year out, has ever had a more enthusiastic, loyal, and effective group of workers. Then there is an equally able headquarters staff, headed by our effective national secretary, Mr. Henline.

"As I think of all of these I look forward to the year with confidence.

"Last year District 2 of which I was then a member was accorded great distinction by having elected from its ranks our president, Mr. MacCutcheon. You need no reminder as to how faithfully he has carried out his responsibilities. Under the impetus of the enthusiasm he has generated I am sure we will continue to go forward. I want to take this opportunity to express great admiration for him, and for the work he has done in the past year.

"Again my deep thanks for the great honor you have conferred upon me. Milwaukee, 1937, is a milepost in my life."

The summer convention is over. Those of us who were fortunate enough to be there will long carry in mind the interesting, instructive sessions, the inspiring talks by Doctor Bush and Doctor Flanders, the inspection trips, the courtesy of those who made the trips possible, the entertainment, and in particular the consideration shown our families.

The Institute has gained new honors from the really superb manner in which the Milwaukee convention program was carried out. As host the Milwaukee Section earned high praise. It is a privilege to express appreciation.

C. H. Harrison

The Engineer and His Relation to Government

By VANNEVAR BUSH
FELLOW AIEE

Whether democracy in America can endure depends in no small measure upon the attitude of the great professional classes in general, and in particular upon the attitude and effectiveness of the engineer in his relation to government, says this well-known engineer and educator, who states further that although there is an enormously complex system of organizations of scientists and engineers in the United States, this mechanism is not utilized to the full in expressing the viewpoints of engineers generally upon important public questions. To meet this need, Doctor Bush suggests that the organization of engineers should be integrated, simplified, and strengthened.

WHATEVER one may conceive to be the future of civilization, whether one is pessimistic or optimistic in regard to the long pull, one thing stands out —we are certainly on our way. The world is full of change. Our systems of government, not only in Europe, but here in America, are in a state of flux. We live faster, occasionally longer, and always in a new pattern of relationships between man and man. We are headed somewhere in a hurry, whether that somewhere be a grand crash, a reversion to a long sleep, or a more abundant life.

The scientist and the engineer started us on this path. They wakened us from the semipeaceful somnolence of a century ago, shrunk the world to a fraction of its former size, and placed the well-oiled wheels of the scientific method under us; and we roar forward in a crescendo of tumult toward the unknown. Now it is suggested that some attention should be paid to the steering gear.

Much attention has been paid to equipping and speeding up the conveyance in which civilization rides, and comparatively little devoted to safety devices. The medical profession has conquered one plague after another, engineers and health officers have extended sanitary measures, and the mentally defective benefit along with everyone else, breed rapidly, and may inherit the earth. Bringing science to agriculture makes possible the production of food by fewer men on less acreage, and our farmers have no place to go. Individual transportation is cheapened, and automobile accidents kill 30,000 people a year. The airplane applies a multiplying factor to the useful lives of busy and creative men, and brings hostile nations within grasp of one another's throats.

Since the dawn of history the acquisition of skill and knowledge has rendered more complex the relationships between man and man. It is the function of government to control these relationships. Today the burdens and responsibility thrown upon government are increasing by leaps and bounds, and government everywhere is staggering under the load. The kaleidoscopic changes we have witnessed in governments of the nations are a direct result of the growing technical complexity of our lives. Every advance increases the rate of advance, in accordance with the law of acceleration of Henry Adams.* Whether democracy in America can successfully carry the modern burden and the burden to come, and endure, remains to be demonstrated. Certainly this depends in no small measure upon the attitude of the great professional class in general, and in particular upon the attitude and effectiveness of the engineer in his relation to government. It is this relationship that is examined in this address.

First, what really is this government of ours? I am not going to review the history of our democratic system, or the details of its organization. Certainly I am not interested at the moment in the affairs of individuals or parties. The important point is that we have a government which is responsive to public opinion. Sometimes, it is true, this is only haltingly effective; but by and large the course of our affairs is determined by what the great bulk of the public thinks and feels. As we all know, small minorities, through effective organization and pressure, can dictate the course of events in limited areas; but not the major trends. We have had striking illustrations of this power of public opinion in recent times. It first, in a reflection of the war enthusiasm, placed prohibition in the Constitution; and then, in a revulsion of sentiment, forced it out again, in spite of a complex legal situation and the strong resistance of well-knit groups. There is no doubt that, in 1936, public sentiment generally desired a continuance of federal social activity, and obtained what it wanted. More recently public sentiment has turned a tide that was running strongly against the power of the judiciary. The final outcome of the present labor movement similarly will depend upon what all the people think.

This is the essence of democracy, and of a government responsive to the will of the people. This we have and this we hope long to maintain. It is the most beneficent type of government that has yet been created by the mind of man. Yet it has its disadvantages and dangers in a complex modern world; and there is serious question as to whether it can be maintained indefinitely under modern conditions. I make this statement with no implications

* "The Education of Henry Adams," Houghton Mifflin Company.

An address delivered at an evening session of the AIEE summer convention, Milwaukee, Wis., June 22, 1937.

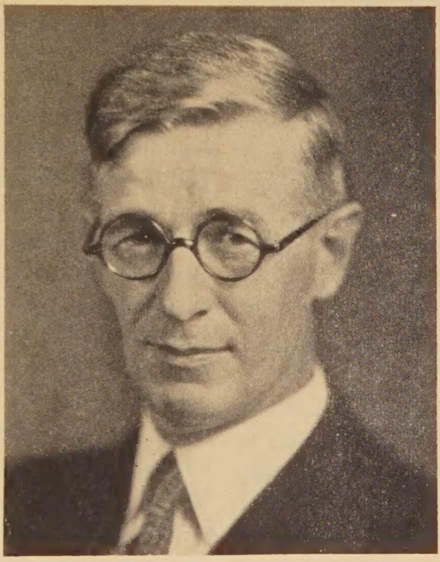
VANNEVAR BUSH is vice-president of the Massachusetts Institute of Technology, Cambridge, and dean of the school of engineering. He was graduated from Tufts College in 1913; in 1916 he received the degree of doctor of engineering from MIT and Harvard University, and in 1932 the honorary degree of doctor of science from Tufts. He is known for both his achievements in research and his contributions to engineering education. He has long been interested in the design of analyzing instruments, and for his work in this field he was awarded the Levy Medal of the Franklin Institute in 1928 and the AIEE Lamme Medal for 1935. Doctor Bush is one of the newly elected directors of the AIEE and has served on many AIEE committees. He is the author of many technical articles, and of "Operational Circuit Analysis" and, jointly with W. H. Timbie (A'10, F'24), of "Principles of Electrical Engineering."

whatever in regard to any individuals or isms. We have proceeded far in this country along the road of democracy. This republic started its career with great detail in its representative form, expressly designed so that the primary opportunity of the electorate would be to select trusted representatives who would then be somewhat removed from immediate pressure. The loss of real significance of the electoral college, the direct election of senators, the introduction of the referendum, have been some of the steps toward that complete democracy in which the people themselves decide on the important questions of the moment. This trend began with the election of Jefferson and has continued ever since.

Yet this enormous country, with its heterogeneous population and interests, is one of few remaining democracies. We witness a movement in the world at large toward absolutism. It has made little difference in the end result whether this has come about by reason of a first move toward the left or the right. We see many nations turning toward the placing of absolute power in the hands of one man, with consequent suppression of individual freedom. Democracies elsewhere have proved unstable. No small factor in this situation is to be found in the fact that the questions of the day are too complex for the people truly to grasp in time.

There is a pessimistic philosophy of government which holds that the trend of democracy toward breakdown and succeeding absolutism by an individual or a class is inevitable. According to this theory, democracies tend to become increasingly more direct, checks and balances gradually are thrown aside, the dependence of the governing group on public whim leads to weakness in law enforcement, respect for law decreases, and finally chaos ensues, to be followed by seizure of arbitrary power by a closely organized minority. Shall this be true of America? Not necessarily. All these dire results were predicted to follow promptly upon Jefferson's accession; and in fact many seriously expected that the Reign of Terror of France would be repeated here. But it was not, and over a century has passed while this republic has gone through stress of the most intense form. There is a counter influence which has saved us from catastrophe. This is the gradual increase in the standard of living, and the intelligent grasp of large affairs on the part of the people. We have also developed in this country a resistance to the forces of propaganda which occasionally manifests itself. So we may yet go on.

For present purposes, it is sufficient to note that our government is now of rather extreme democratic form, and that public opinion controls its trends in large affairs. Its governing bodies and executives, therefore, are bound to be men who are sensitive to, and able to cope successfully with, this opinion of the public.



Doctor Bush

In this form, our government is called upon to decide momentous technical matters, most of which are so complex that they can be fully understood, if at all, only by experts. Such questions involve finance, sociology, economics, engineering. They cannot be grasped completely and intelligently by the general public. They cannot be grasped by the elected representatives of that public, who must in the nature of things, be specialists principally in the political art. How then are they to be decided wisely in a democracy?

Much depends upon the answer to this question. We are in competition with nations in which absolutism and intense nationalism control. The maintenance of our position, our relative standard of living, depends upon the skill with which our affairs are handled. Under an absolute ruler all specialists of every sort become government specialists. A dictator can make final, binding, prompt decisions upon weighing their recommendations. Will we, with our exceedingly loose system, be similarly able to bring to bear the best of intelligent judgment upon the technical problems of the day? We must do so, if we are to hold our place. Our frontiers have vanished; the surge of a pioneering people cannot indefinitely carry us forward; we are making rapid inroads upon our unique national resources. The day is coming when our progress will lean heavily on the intelligence with which we treat our public questions.

The age-old struggle between those who have and those who have not is distinctly modified by advancing standards of living. A greater proportion of the people become property holders, and this tends toward stability and orderly processes. Yet the trend proceeds slowly, and the struggle is far from termination. We still face a clash of interests which is as old as history, between those who control our social and industrial systems, and the great mass of people who labor. Whatever the political system, whatever changes in the character of our institutions may come, this situation will always be with us, for someone must always control; there must always be those who issue orders, benignly or harshly, if the industrial mechanism is to function. It is the proper sphere of government to control and regulate; to set up and enforce the rules that will insure efficiency and equity, to protect minorities,and to deal with other nations. For government to step in and itself become the manager of industry is a mistake. There is no longer an umpire in the field. The lines become drawn between the people and government itself, and this is the beginning of disaster. We cannot afford, in this country of ours, to have an umpire who also plays on one of the teams.

What Distinguishes a Professional Man?

Standing aside from the industrial system, and yet intimately connected with it, are the great professional classes, of which the engineer forms a part. What renders a man a member of this professional group? It is much more than the possession of special knowledge, although this is a necessary attribute. The skilled machinist possesses special knowledge, as does indeed the man who owns and manages a machine shop; yet neither thereby is constituted a professional man. It is more than the nature of the source of income. True, many professional men, physicians and lawyers especially, derive their income from fees from clients. Yet a clergyman is usually on a salary. The majority of scientists are similarly paid by universities and scientific institutions. The great proportion of engineers are employed regularly by industry on a salary basis. Definite association with a specific organization on a salary basis does not bar a man from rightful membership in the professional class. The distinguishing characteristic is the possesssion of a philosophy and a point of view. The true criterion lies in the basis of motivation of the individual.

In any society there are 4 primary classifications of individuals. First is the great body of artisans who carry on the work of the world. Second are those who manage and direct, deriving their power rather directly from the possession of the facilities for production, or indirectly by delegation from the actual owners. Third stand those who govern. Finally come those whose primary mission in life is to acquire learning and render it usefully available to those in every classification. These last form the professional group.

It is possible for an individual to belong simultaneously to several groups. The farmer is often a worker and a manager. The owner, to whom management is at least formally responsible, may comprise hundreds of thousands of stockholders in all walks of life. He who governs may derive from any group. Similarly, the professional man may adhere also to other classifications. But if he loses his philosophy, if he ceases to regard the acquisition of knowledge for the public welfare and rendering it available to all groups as his primary mission in life, he no longer is truly a professional man.

The late Arthur D. Little in an essay* delivered before the Franklin Institute, defined the "fifth estate" as: "those having the simplicity to wonder, the ability to question, the power to generalize, the capacity to apply. It is, in short, the company of thinkers, workers, expounders, and practitioners upon which the world is absolutely dependent for the preservation and advancement of that organized knowledge which we call science. It is their seeing eye that discloses, as Carlyle said, 'the inner harmony of things; what Nature meant.' It is they who bring the power and the fruits of knowledge to the multitude who are content to go through life without thinking and without questioning, who accept fire and the hatching of an egg, the attraction of a feather by a bit of amber, and the stars in their courses as a fish accepts the ocean."

It is the high privilege of the engineer to aspire to genuine membership in this distinguished category. The possession of an academic degree is not sufficient to admit him. Success, as measured by his income, does not admit him either. The humble Jesuit parching amid the sands of the desert that he may bring light to the lowly, and the country physician struggling through the storm to relieve suffering, need no decoration of material success to mark them as honorable members of the group. Recognition by colleagues, based upon true scholarship, untainted by self-advertising—this is the reward. Completely free from prejudice as to class or race, laboring for the ultimate good of society at large as he envisages it, above passion, secure in the possession of special knowledge which the world needs and hence independent of the whims of individuals and groups, the true professional man is and should be a figure apart, wherever he may be placed. It is his duty to merit that confidence which alone will permit him to operate with effectiveness.

Government Needs Influence of Engineer

There is all too little respect for law in this country. There is also all too little respect for genuine scholarship. Fundamentally the influence of the professional group depends upon the development of this respect. Only thus can its influence be effective. The trend of affairs can be molded by those who have seen the light only in so far as they are welcomed into the counsels of the groups of the population. The influence of the professional man is sorely needed in these times. Managers of industry have been keen to grasp its peculiar advantages, and there is no lack of contact at this point; but unfortunately it often arises under conditions that render difficult the maintenance of true professional status by the professional man. But government most needs the influence. At this point in this country we proceed haltingly. The influence of the engineer upon the processes of government is especially necessary if there is to be sanity in public affairs. How then may it be enhanced?

The professions of law and medicine exert strong and generally beneficial group influence through their national professional organizations. The profession of engineering does not. No great legal change occurs without scrutiny and pressure from the American Bar Association. No move for the regulation of medical practice proceeds without the prompt, effective participation of the American Medical Association. Great engineering works are constructed in this country, and the group opinion of the body of engineers thereon is not even expressed, with results that are sometimes ludicrous. We have no reason to be proud of the influence of engineers on the course of government as it affects engineering. By and large our efforts have been pitiful.

There is a striking difference in the relationships of these 3 great professional groups to government. Many members of the legal profession are essentially part of government itself, since they fill our legislatures, sit on the judicial bench, and practice as elements of the court. At

* Centenary celebration of the founding of the Franklin Institute, September 17, 1924.

the opposite extreme is the medical profession, most of whose members shudder at the thought of governmental medicine and have their heels dug into the ground to resist the present tug in that direction. In between are the engineers, who are more and more becoming closely allied with government as the technical aspects of government activity intensify. We do not know whether, as a group, they resist this trend or not. Apparently they haven't even begun to think about it.

Organization of the Engineering Profession Is Highly Complex

It is said that, where 3 Americans foregather, there soon will emerge a president, a treasurer, and a secretary. One might add to this that often when learned men associate themselves there will be found an intangible complex organization beyond the mind of man to fathom. There seems to be direct correlation between the scholarly attainments of individuals, and the looseness and ineffectiveness for action of the associations they create. The greater the grasp by a group of the intricacies of a social problem, the less likely is it to present a united front on anything whatever. The rate of progress of a group toward a single objective varies inversely with the number of members thereof, and inversely as the square of their special knowledge. The scheme of organization of the professional groups in this country is a marvel to behold. Those of the lawyers and the physicians have effective elements which have been noted. That of the scientists and engineers is a tangled maze in which most of the participants become lost. I think I can fathom something of the way in which our complex political system operates. I have been a member of many professional organizations for many years, and I have yet to form a rational picture of their activities. Their journals get a quick glance as they zip across my desk toward the sagging shelves. They collect dues with growing persistency. Yet the government digs a hole in the sands of Florida to no proved good purpose, and I hear no voice raised to say that we, the engineers of this country, insist that we be told authoritatively what the economic and engineering complexion of that particular hole really is. Much less do I gather that the hole will not be dug except when it has the blessing of the organized engineers of the country. The trouble is they are not really organized for this effective purpose.

In 1933, the *Technology Review** attempted to sort out the 900 scientific and technical societies listed in a handbook of the National Research Council, and to present something of an organization chart and family tree of the engineering societies included. The tree developed into something of a forest. True, one might construct an imposing list of medical or legal societies devoted to special interests. The difficulty is that the engineering group of societies does not head up anywhere. We are especially interested in the way in which this situation influences the relationship between engineers and government, so it will be examined somewhat in detail.

It is right and proper that there should be many organizations devoted primarily to special technical interests, and the increase of these is inevitable as the interests of engineers fan out. Yet it is far better that this development should occur by subdivision of large national societies, rather than by the creation of new groups with consequent increase in overhead costs, and lack of co-ordination of interests. The American Institute of Electrical Engineers, last of the 4 Founder Societies,† was founded in 1884. Since then have appeared the American Electrochemical Society, the Illuminating Engineering Society, the Institute of Radio Engineers, and others representing special interests within this general field. A similar disintegrating tendency appeared in the group of societies dealing with all aspects of physics, but in 1931 the creation of the American Institute of Physics regrouped these to secure closer interrelation, and economies in publication. No comparable integrating tendency among the Founder Societies has yet appeared. The most important question however, is that of attempts to integrate engineering societies as a whole.

The 4 Founder Societies are associated, through the United Engineering Trustees, Inc., for the purpose of managing a building used in common, for the maintenance of a library, and to sustain the Engineering Foundation "for the furtherance of research in science and engineering, and for the advancement in any other manner of the profession of engineering and the good of mankind." Excellent as is this joint effort, it is directed in practice primarily toward the attainment of technical objectives, and does not properly touch the relationships of engineers generally to government.

The Founder Societies, together with the American Institute of Chemical Engineers, the Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners, joined in 1932 to create the Engineers' Council for Professional Development. This "aims to co-ordinate and promote efforts and aspirations directed toward higher professional standards of education and practice, greater solidarity of the profession, and greater effectiveness in dealing with technical, social, and economic problems." Its activities have been pointed primarily toward young engineers, through the certification of engineering schools in connection with state licensing programs, and the postacademic education of engineers. It is doing excellent work in these fields, but does not aim to ascertain and impress group opinion of engineers on governmental or social problems.

Central Engineering Organizations Already Exist

The nearest approach to a mouthpiece for engineers generally on important matters is the American Engineering Council founded in 1920 "to further the public welfare wherever technical and engineering knowledge and experience are involved, and to consider and act upon

* *Technology Review*, July 1933, page 330, "Engineering Societies, their Multiplicity, their Relatives, their Duplication."

† The others are: American Society of Civil Engineers; American Institute of Mining and Metallurgical Engineers; and The American Society of Mechanical Engineers.

matters of common concern to the engineering and allied professions." This is exactly what we have in mind. Yet the engineer, with all his supposed genius for organization, has not rendered this the effective instrument that is sorely needed. Every country doctor knows of the American Medical Association. He may quarrel with its dicta; but he knows that with a host of others he influences its pronouncements, and he is proud that it represents him. I would be willing to wager that a survey would show that a large fraction of engineers in this country do not even know of the existence of the AEC. Certainly the average engineer has no feeling that his influence is brought to bear even indirectly upon their considerations of important public questions. It has not the intense interest and support of the profession generally, and its expressed opinions are to this extent ineffective. A devoted group of engineers deals meticulously with the affairs of AEC, and undoubtedly the situation is not their fault. It is none the less regrettable. There are some evident contributing factors to the situation: The average engineer pays no dues to AEC, sees no direct publication of AEC, and takes no direct part in the selection of this body of men who convene to decide upon the problems of the day. Pronouncements have not been strikingly timely. The engineering profession has held important group opinions, but has not seen them forcibly enumerated and spread on the front pages of the newspapers.

If the engineers of this country do not recognize and support their spokesman in the AEC, still less do they recognize that they have a duality of spokesmen. The American Association of Engineers was founded in 1915 "to accomplish for the unity, welfare, standards, and public recognition of the engineering profession what such organizations as the American Bar Association and the American Medical Association have accomplished for their respective professions." It has the slogan "proper recognition to the engineer and the engineering profession," awards a medal, provides group insurance for its members, and has been active in vocational guidance.

There are 3 laudable ideas involved in this matter of a central engineering organization. First is the furtherance of the interests of the profession. Second is the bringing to bear of the influence of the profession upon public matters. There should be no confusion between these. While it is highly fitting and proper that engineers should be active to guard their own interests, such activity is apart from the higher mission of influencing public trends for the benefit of the entire public. These are combined in the same organization only at the risk of weakening the latter. The attention of the AAE is primarily devoted to the former. The third laudable idea is that of direct advice to government departments or agencies on their specific problems.

National Academy of Sciences Was Founded to Advise Government

On this third aspect the engineering societies function primarily only through a more general organization of scientists. The National Academy of Sciences was founded in 1863, by act of Congress, approved by President Lincoln "to advance science and especially to investigate, examine, experiment, and report on any subject of science or art whenever called upon by any department of the Government of the United States." It is a limited-membership self-perpetuating body, similar to the scientific academies of the old world. One of its many sections is composed of engineers. In 1916 its activities were implemented when it formed, at the request of President Wilson, the National Research Council for "the promotion of research in the physical and biological sciences, and the encouragement of the application and dissemination of scientific knowledge for the benefit of the nation." After the war the NRC was perpetuated by an executive order of May 11, 1918. Still later, and again in time of emergency, this organization was extended by the creation, under the Academy, of the Science Advisory Board, which reported on many important matters referred to it by government departments. The term of this board now has expired, and it has been superseded by a committee of the Academy. This whole organization is itself extremely complex.

By the very nature of this organization, it does not function to bring to bear upon great public questions the opinions of scientists, except when called upon and then in connection with definite scientific problems. In such matters it has rendered important aid and advice. One important aspect of its affairs has been to set up advisory committees for scientific bureaus of the government. Its active arm in research, the NRC, administers research funds for government and large groups, and correlates and promotes scientific research generally.

This is the official established mechanism by which government may call for the opinion of scientists generally, and engineers in particular, upon technical problems, for it was created by government for this specific purpose. Government does so call, and does thus receive advice and counsel. Questions involving important engineering matters, such as recently the problems of ship stabilization, and of lighter-than-air craft, thus are given the benefit of review by distinguished men. Such a controversial matter as the economic and engineering justification of building a tide-power plant on the coast of Maine, however, does not travel by this route. If government asked the question, it would obtain an answer; but it does not ask the question. The mechanism is available, but the pressure necessary to ensure that it will be used is absent. True, engineers are here joined with all types of scientists, but nevertheless the query would result in the gathering of a distinguished group of engineers and economists to deliver the answer. Later, I will discuss the function of the independent consulting engineer in this connection, but at this point I merely note that his services, under proper fee, are not at all inconsistent with the presence of distinguished voluntary committees of review.

One more organization remains to be mentioned. The American Association for the Advancement of Science, founded in 1848, is the great democracy of science in this country. This loosely knit organization comprises about 150 member societies, with half a million members. One

section with many member societies, is devoted to engineering, but engineers generally take no part in its activities. It serves the very useful purpose of bringing together diverse scientific groups for great annual meetings at a common point. Its council occasionally adopts resolutions on public questions, but legislators do not hang on its words. Its membership is too casually affiliated to render it a powerful voice in national affairs.

The engineer, who applies science in an economic manner for the benefit of mankind, certainly has as close common interests with the social scientist as with the physical scientist. Yet the organizations of the social scientists are not greatly participated in by engineers.

Since the beginning the engineer has co-operated closely with the physical scientist; and in fact many engineers are themselves physical scientists of no mean accomplishment. We have reached the point where engineers are learning to work in similar co-operation with social scientists, but the relationship must proceed much further than this. It is necessary, in connection with many of the problems that come to him, that the engineer be himself a social scientist—not a dilettante but a deep student and scholar in his own right in various branches of the social sciences. Only thus may he be properly cognizant of the source from which his activity derives, and also properly cognizant of the social conditions under which it becomes applied. Long familiar with applied economics, he now finds pressing upon him other branches of the broad science of human relationships. The colleges have a duty to perform here, and so have the professional engineering societies. Certainly their meetings and publications should generously reflect this growing need and interest.

Integration, Not Another Society, Needed

To summarize this matter of organization: Real attention is being given to the professional advancement and the technical interests of the profession. We have an enormously complex system of organization of scientists and engineers in this country, and yet no effective single central organization representing *all* engineers and expressing their viewpoint on public questions. We have an elaborate mechanism for bringing advice to bear on scientific and engineering problems as they arise in government, and this mechanism is not utilized to the full.

What is to be done about it? Certainly no solution lies in forming one more society to join the throng. Integration is indicated; and since societies now exist for all the express purposes we have considered, a duplication of effort by a newcomer would simply complicate matters. Rather, the existing mechanism should be simplified and strengthened.

Would it be of aid if the great national organizations, such as the AIEE, were to take official and definite positions on public questions involving engineering? I do not think this is their proper function, for reasons I will discuss. This is being done in some such organizations, and the effect so far has not been especially helpful. It is another thing entirely for the AIEE to provide a forum for the frank discussion of important questions by men of all shades of opinion. In this I believe it has a duty to perform. So far it has not been done, and the reason seems to be that those in control have not had the courage to take a step which they fear would split the society. Perhaps a frank and fearless discussion on the floor of an AIEE convention of such a problem as that of the proper sphere of activity of government in the generation and distribution of electric power would split the society. I do not think it would. This is certainly a matter of present interest to electrical engineers. If those who are best able to approach it dispassionately and intelligently fear to open the question at all, how is public opinion to be influenced? In the membership of the Institute are men who hold all sorts of opinions on this subject, many of them violently. Many will not express their honest opinions because of their affiliations with government or with public utilities. But there are many more who can and will bring light upon the subject, and, like all subjects of great controversy, it has at least 2 sides. When I speak of a free forum in this connection I do not mean one where the floor is open to the public. I have in mind one where the participants are carefully chosen for their ability to present their views clearly and calmly, and carefully chosen to bring out all shades of opinion. Such an airing of views on this and many other matters would do a great deal of good. A similar benefit will result when professional publications carry powerful expositions and arguments on the live issues of the day, again with an opportunity for accomplished representatives of all sides to be heard. But the Institute itself should express no opinion on this or any other controversial question where its membership holds diverse views. It cannot at once be the guardian of a free forum and an advocate. Still it should certainly not be an ostrich.

This taking of stands should be left to a body having that as its primary function. That body should be made up of men of great distinction in the profession, chosen for the purpose by the membership of the profession directly. It should use every legitimate means to be well known to the membership, by questionnaires, publications, and by reasonable publicity in regard to its deliberations and findings. It should be absolutely without fear and without prejudice. Its pronouncements should be front-page news in every corner of the land. It should enter into any public question involving engineering as a right and without invitation. It should not hesitate to swing public opinion by rousing the profession when such action is indicated. In order that it may speak with a single voice it should represent engineers only, with deference, of course, to the opinions of other professional groups. We do not have this situation today. The metamorphosis of existing organizations, under the guidance of public-spirited engineers, may bring it to pass. As it proceeds it should have the aggressive support of every engineer who has the good of his country at heart, whether or not he agrees with its findings in every respect.

The technique of applying the pressure of engineering opinion on great public questions is only one aspect of our problem. Another aspect involves the advice by engineers to government on specific technical problems. This is a

large question and one that involves many of us in one way or another, as citizens and taxpayers as well as engineers.

Government Needs Independent Consulting Engineers

That there is an elaborate mechanism by which government departments may secure the advice of scientists and engineers, has been shown. For several reasons, this is not sufficient for the purpose. First, the way is indirect, through an organization that is preponderantly scientific. With the best intentions in the world such an organization cannot function precisely and promptly to bring to bear on a great national engineering problem the best engineering brains to be had anywhere; only a few of the great engineers of the country are directly affiliated with it; and the indirect path is cumbersome. The complexities and inertia of this situation were overcome in time of war and in time of great depression, but during normal times the mechanism works feebly. Second, to wait to be called upon in a busy world is not enough, and the present organization has a natural and proper hesitancy to press itself into controversies. Third, the setting up of distinguished boards of review on a voluntary basis is not enough.

One cannot give sound advice on important engineering matters without spending considerable time and money. This is the function of the independent consulting engineer. We will not be on sound ground in this country until government, on a basis of adequate and dignified fees, calls for the opinions of independent consulting engineers whenever it has an important engineering problem. This it does not do at the present time to any determining extent. If, when the subject has been deeply studied and reports have been presented, the government wishes review by distinguished boards, it always will find men ready to give their services as a matter of public duty. The main reliance, however, must be upon independent consulting engineers, and I wish to make a plea on their behalf.

There are many engineers—many able engineers—in government itself, and these are utilized by government when it has an engineering project to carry out. Army engineers have carried forward on a high plane many outstanding engineering works. The Reclamation Service conducts a research laboratory that is second to none. But the government engineer is not an independent engineer and the latter is sorely needed. Given a definite project the government engineer can carry it forward; but he cannot at the same time say that it is a foolish thing to carry out at all, even if his engineering studies convince him that it is. Here is a point at which a democracy is at an advantage compared with an absolute government. The dictator has *only* government engineers—units in a rigid machine. Independence of thought and speech there cannot be tolerated. Yet, having the advantage as a democracy of the presence of engineers of real independence, we do not make use of them. This is partly because truly independent engineers are becoming rare; partly because unfortunately government is sometimes not anxious that the full truth be known; partly the fault of the engineers themselves. This matter is worth discussing briefly, for it is truly unfortunate if one of the great assets of a democracy is being thrown away.

The rise of great industries in this country, with their own engineering organizations, has restricted the field of operation of independent consultants. The tendency to extend free engineering services as part of the sales programs of large companies similarly has encroached. Fortunately, industry by and large cannot maintain engineering departments capable of coping with the unusual, and these peaks are surmounted by calling in the temporary services of independent engineering organizations. Yet the way of the consultant has not been easy, and the number of men who are truly independent, who have seasoned opinions based upon wide experience in many fields, is not large. This is distinctly the fault of government. There should be more utilization of men of the type of John F. Stevens called for service at the Panama Canal. If it were our practice in this country for government to employ independent engineers frequently, the number of such engineers would be greater. When government calls on the engineer at all, it usually attempts to do so on a niggardly basis. It appears to attempt to starve out a group upon which it distinctly needs to lean.

But part of the fault lies with engineers themselves. While we deplore any reluctance on the part of government to let the full light of reason play on its plans for engineering works, we must admit at the same time that the approach of engineers often has not been based upon a sufficiently broad consideration of these very matters. To show that a government engineering work will not pay an adequate financial return on the original investment is not necessarily sufficient to condemn it; yet engineers are prone to limit their considerations to a strict cost and yield basis. The building of a battleship cannot be justified on this basis. The setting aside of a national forest should not be thus approached with limited logic.

Do not think that I advocate letting down the bars of strict reasoning to which all engineering works should be subjected. I have no sympathy with any waste of public money. To build a great dam to supply electric power in a region already amply supplied with power, to irrigate land in a region of no inhabitants while farm land stands idle close by, to render navigable a stream that proceeds into a wilderness, are fool pieces of work in any language. Yet I would have the engineer join with the economist, the sociologist, the student of government, that he may grasp problems in their entirety.

Is it foolish to clear slums, and to cause living quarters to be built by subsidy from public monies, for the use of previous slum dwellers on a rental basis that returns only a portion of the direct investment? It may or may not be, and the answer can come only when the engineer works with the sociologist. It may be a decidedly good investment on the part of government from a strictly financial point of view, if the decrease in costs of police, health hazards, hospitalization, and social decay, which follow slum clearance, offsets the direct cost of subsidy. But merely because the problem involves more than the matter of direct costs and direct revenues, does not excuse government for proceeding without independent advice;

it merely emphasizes the need for analysis by professional men of diverse types.

Consulting Engineers in Educational Institutions

Both government and industry should support the independent consultant in this country, that he may be available in time of need. A duty also rests upon our educational system in this same connection. This duty may rest lightly, for the consultant with university affiliations can bring strength to the educational system itself. Much has been said on this subject, and some would block consultation by members of college faculties. This always would be a catastrophe, but especially so at present when the consulting engineering profession needs to be enlarged and supported. Moreover engineering education must be real, conducted in an atmosphere of success, and in close contact with industrial and governmental advance; and the consultant on the faculty can aid greatly in this regard. There are dangers in the relationship, of course, but they can be avoided and the benefits secured. The use of the name of university affiliation, without the substance of educational duties and responsibilities on the part of the consultant, is a perversion. Encouragement of consulting by university administrations should be accompanied by insistence that such contacts be on a high plane and such as to advance the professional standing of both the individual and his institution. The fees charged should be on a dignified basis and such that there is no unfair competition with consultants who do not combine educational activities. There should be no use of university laboratories in consulting connections except where the institution is fully reimbursed for all costs of having the facilities present, and then only when there is no interference with the use of these facilities for their primary purposes. Educational institutions that have unique research facilities not available elsewhere, should make them available as far as possible without impeding educational use, either directly or through those commercial organizations which perform research services for industry. This certainly does not mean, however, that an educational institution should do routine testing for industry where there is a commercial organization capable of performing the work. Industrial research within an educational institution may be a fine thing, when it carries its full costs, when its results become published, and when its presence adds to the educational process of training men capable of coping with industrial research problems after graduation. But neither the educational institution itself, nor the consultant who is a member of its faculty, should carry on activities that tend to lower the plane of independent consultants or independent commercial research laboratories. When these matters are realized, the presence of a consultant on a faculty may be of benefit to the institution and render available one more independent engineer for advice to government and industry.

There are many ways in which the individual engineer makes contact with government, and several in which a more intimate contact would be of benefit. One important way lies in the growth of the commission form of activity. These commissions usually, as in the case of the Federal Communications Commission, the United States Shipping Board, and the Tariff Commission, are essentially groups of experts within the frame of government itself. So also are such units as port authorities, irrigation district authorities and the like, set up within our still flexible frame of government to unite the administration of regions having common technical character. These and similar units offer one promising mechanism by which to implement the specific actions of government in technical affairs. The engineer is an important member of all such bodies. By and large they have been decidedly effective. An important element, however, appears to be generally lacking in the movement. Usually such boards depend upon the technical knowledge of their own membership, supplemented only by the examination of witnesses who come before them. They are not amply enabled, by the act which establishes them, to increase their grasp and power by temporarily joining to their membership outstanding consultants with special knowledge of the particular problems before them. The independent engineer would find in such association many opportunities to be of genuine service.

Engineers and the Legal System

Another important way in which the engineer makes contact with government is in connection with the legal system, both in law enforcement and in the administration of justice in the courts. This is too large a matter to be treated adequately in an address having a broader subject, yet the point comes up inevitably. There is a real need for close association of scientists and engineers with the legal system at many points, especially in the patent system. The reason is clear. The determination of any legal question depends jointly upon the law and the facts. In a modern technical world the facts are beyond the comprehension of the layman. When dealing with a scientific or engineering subject, the most eminent jurist or attorney is usually decidedly a layman. The result is often sad. Decisions are rendered by judges to whom the facts of a case are in essence imcomprehensible. Present procedure is expensive, indeterminate, and sometimes ludicrous. Details of procedure aside for the moment, the real reason for this situation is the unwillingness of the legal profession to admit to a basis of partnership the scientist who understands the technical facts of modern civilization, with the attorney who understands the law. We have the spectacle of opposing experts, cross-examined by lawyers who have a week's cramming as a background in the subject under consideration, for the benefit of a judge whose scientific training ended at "Physics I." The childlike faith of most attorneys in this process of elucidating technical facts is beyond comprehension. To the technical man on the sidelines it is often evident that the discussion proceeds to about page 20 of an elementary text, when the true answer lies on page 500 of an advanced treatise. The general atmosphere, charged with suspicion, progressing at a snail's pace, is such that the majority of scientific men engage in legal matters just as little as

possible. To expect men of great scientific attainment generally to be willing to take part in this procedure is expecting a great deal from the human race. Yet the members of the legal profession generally regard the presence of a technical adviser to the court, not subject to cross-examination, as an anachronism, and they are perfectly sincere and honest in the opinion. The dilemma is clear. The legal profession, which controls the system, cannot itself or through its artifices deal justly in the type of world in which we now live. It will not have the true co-operation of the best scientific and engineering minds in expeditiously arriving at justice until it welcomes them to something besides a subordinate status. In some of its phases, the legal system has been dangerously close to breakdown, and no small portion of this situation is the extent to which it is bogged down in a scientific morass. If breakdown comes, it will be the fault of the profession that molds its affairs and determines its form. Scientists and engineers stand always ready to aid in a matter of public concern and on a basis of professional partnership. In this connection the independent consulting engineer can be of real service in many ways, but space does not permit a detailed examination of them.

Throughout this address I have emphasized the value of independence. So long as this is maintained and there is the effective guidance of affairs by an independent professional class, I have no fear for the future. A true democracy, given this support, can compete with dictatorship and prevail.

Frontiers of Science Still Remain

It was independence of thought, freedom of action, the opportunity of a vast untamed domain that built this country and gave it the highest standard of living in the world. The geographical frontiers have disappeared, but the frontiers of science and technology still remain. Those qualities which built a trail into the wilderness can still build trails in the technological advance. The same qualities of courage, resourcefulness, and independence which opened the nation, are as necessary today as ever.

The growing complexity of life tends to make men cogs. The world is growing smaller, and it is becoming crowded. We "rub elbows" and find increasing dependence upon the activities of our fellow men. The race for economic domination becomes a race, from which we only partially are separated, for military supremacy. The burden on government increases, and the problems arising are more and more beyond the true comprehension of the proletariat. Intense nationalism is in the saddle, and everything, including freedom itself, toward which the human race always has aspired, is being sacrificed for a momentary advantage in the struggle. Nations are turning toward absolutism as a refuge.

Gladstone predicted the decay of democracy if the indigent voter found the power of his vote sufficient to seize arbitrarily and unreasonably the fruits of production. Jefferson himself, the father of American democracy, postulated as a necessary feature of a democratic régime that the bulk of the voters must be tillers of their own land. Whatever we may wish to modify in these opinions, one thing should be added in view of modern conditions. As the social machine becomes more complex and interdependent, it becomes increasingly easy for an aggressive group to disrupt it. The need for discipline is greater, the necessity for restraint of the asocial individual or group is more pressing. Individual freedom, always circumscribed, from the clan up, by the necessity of consideration of the rights of others, becomes inherently narrowed. The right to do this or that ceases to be a right when its performance injures a neighbor; and the ways in which each individual's acts reflect upon the security of his fellows are constantly multiplied. The democratic form of government is adapted to the maintenance of discipline only to the extent that great groups of varied peoples are ready and willing to discipline themselves. The failure to do so in other countries is the primary reason that the people have reverted to absolutism in the hope that it would prove benign. The immediate result of course, has been to impose discipline, often harshly and in the extreme, to curtail radically individual freedom, and thus to create a state in which efficiency is secured at the sacrifice of much that makes life worth living. The plunge into absolutism is abrupt. The winning of individual liberty is a slow and painful process. Must all democracies go through this cyclic process? Can the great populace, which is governed by its intuitions, its emotions, its mass psychology, grasp this trend and preserve its stability? Moved by the persuasion of those with ulterior interests, who play upon their emotions, can they yet understand the voice of reason? It depends upon whether those who would bring to the people the accumulated wisdom of the ages speak in words that are powerful, genuine, and capable of being truly understood; and then it depends only upon whether the people listen and are willing to be guided by reason.

Professional Man Should Make Himself Heard

The free operation of professional classes, motivated by public zeal and altruism, is an anchor upon which our democracy depends to hold it through the storm. There is a great obligation upon the professional man to speak clearly, to insist upon being heard, to maintain his independence. This obligation rests heavily upon engineers.

To be a professional engineer in the true sense, does not require that we have some special set of relationships to society and to the organizations of which it is made up. It does require that the primary motivation be the acquisition of scholarship and its generous application to the needs of man.

To be an engineer in these days is to bear a proud title. To be able and willing to speak true opinions on the complex technical affairs of the day, without prejudice and free from control, is a privilege that is becoming rare in the world. Insistent upon his prerogatives, kowtowing to no man, respected because he speaks a truth the country needs to know, the independent engineer stands as an important member of the professional class—a strong bulwark against disaster, which can guide our steps into the ways of pleasantness and into the paths of peace.

The Engineer in a Changing World

By RALPH E. FLANDERS

What can and should engineers do about the social and economic problems that beset the modern world? In answering this question, Doctor Flanders says: "We must exercise our responsibility more for the sake of society as a whole than for the sake of ourselves as individual engineers or for the private interests of the businesses with which we may be connected." He states further that: "It is an inescapable duty that we each make of ourselves centers of education and influence, to the end that our useful offices may continue, and our civilization fulfill its destiny of an ever-growing service to the needs of mankind."

THE WORLD in which we are living is changing in many ways, and those changes are rapid. The physical frontier has disappeared from this continent and, except for the antarctic regions, it has practically disappeared from the earth as a whole. With the occupation of the frontier has gone one of the powerful automatic stimuli to private enterprise and material progress.

Much of the progress we are making is so based upon elaborate research and requires such extensive and expensive provision of facilities that it is best carried out by large corporations or well-financed research groups, rather than by individual scientists, engineers, and inventors of the old type. This is another influence that tends to restrict the expansion of individual initiative and tends to throw the burden of further social progress onto aggregations of capital and of men.

A further element in our increasing socialization is the recent rapid sensitizing of the social conscience and a resulting expansion of social activity into fields of action which in past generations had been considered reserved for the individual or for small social groups. The severity of the depression was so great and the social responsibility for it seemed to be so definite that both our relief measures and our recovery measures have tended to be social and political, rather than individual and philanthropic.

Finally, though without exhausting the list of recent developments, we have become aware of the fact that in our banking, credit money, and general aggregate of financial institutions, we have a useful but delicately balanced, and at times unbalanced, mechanism difficult to control and tending on the whole greatly to increase the violence of business fluctuations and economic distress, rather than to provide a dampening effect on them. All these phenomena and others not mentioned pose a new set of problems to the engineer and to the engineering societies in which they are organized.

In their beginnings and until recent times, engineering societies had the purely technical purposes of bringing to the attention of their members all the latest technical developments in their fields and offering a forum for criticizing them, advancing them, and disseminating knowledge about them.

Even while this type of activity remained almost the sole object of society action, the problem nevertheless began to be complicated by the numerous divisions into which engineering work began to elaborate itself. Engineers were no longer simple engineers. Some were in control of their own businesses as consultants or manufacturers of engineering apparatus; others were employees of various grades. Some were engaged in teaching; others in research, design, construction, sales, operation, and administration. This multiplication of function brought a host of new problems to the engineering societies, on the one hand opening new opportunities to usefulness, and on the other tending so to elaborate engineering activities as to lose much of the harmonious directness and strength of the earlier days.

As a result of the tendency for engineering advance to be focused in and to be carried out by large aggregations of men and of money, the problem of the engineering society has been complicated further by widespread sentiment in favor of entering employer-employee relations, so that in the extremes of such policies the societies might be tending to take on some of the aspects of trade-union organizations.

This continuous elaboration of function is here described and emphasized so that we may realize that the problems facing us are no longer simple, and that any endeavor forcibly to keep them within too simple lines may result in giving to the societies a cloistered and sterile outlook, devoid of vital function and social usefulness. We are in fact faced with the problem of maintaining our social usefulness and finding out just what are the spheres in which it most clearly may be demonstrated and exercised.

World of Today a Product of the Engineer

The world we know has been made by the engineer so far as its physical aspects are concerned, and his influence has had no small part in determining its spiritual environment.

An address delivered at the general session on the economic aspects of engineering and Institute activities held during the AIEE summer convention, Milwaukee, Wis., June 23, 1937.

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Perhaps some remember the epitaph of Sir Christopher Wren, the architect, engraved on the walls of his masterpiece—St. Paul's Cathedral in London. It reads: "Si monumentum requiris, circumspice," or, in English, "If you seek his monument, look about you." In like manner, if we wish to inquire as to the material influences of the engineer, we have but to look about us. We will see thousands of daily reminders of the fact that our material civilization has at the bottom an engineering foundation.

Its useful services are many. Our profession has filled the world with a profusion of comforts and luxuries which were denied to kings a short century ago, but are now enjoyed by the average citizen. Flowing water in the kitchen and bathroom, brightly lighted streets, and the radio, are all ordinary conveniences for the ordinary citizen. They were nonexistent when Queen Victoria began her reign.

There is no need to multiply instances. The tale has been told and retold; but told and retold, as well, has been the story of the problems an engineering civilization has posed for the solution of its citizens. The perils of drought and pestilence have been exchanged for the mischances of technological unemployment. That unemployment may be transitory and a part of a process which history shows to be benevolent in its total results, but it is as yet a serious and sometimes insoluble personal problem.

Worst of all, our engineering civilization proves to be less stable than the older forms based upon subsistence agriculture. It gives us more, but its gifts are more irregular. There are seasons of outpouring and seasons of withholding. Boom follows depression, and depression follows boom, and this relentless alternation leaves much human wreckage in its wake. What can and should we engineers do about the evil features of this world we have made?

Engineers Should Not Intrude Into Alien Fields

It is not my intention to go into the details of this problem. I believe that the engineer's work has been healthy and constructive. I believe that the maladjustments have come from our narrow and selfish activities as industrialists, workers, farmers, and financiers, and from the imbecilities of our politics. In particular, I do not believe, as so many have urged, that the remedy lies in the intrusion of engineers with engineering methods into the alien fields of politics, economics, and finance. This subject will be discussed briefly, because in popular opinion our profession alternately has been damned for causing all the ills of our era on the one hand, and on the other for not curing them by still more radical engineering activity.

This question was raised some months ago in an address by Walter Lippmann, and I take the liberty of quoting here in part from his criticisms and in part from a reply to them:

> There were several years, I should say roughly from the crash of 1929 to the end of 1933, from the breakdown of prosperity to the beginning of recovery, when the ideal of an engineered and planned economy had almost completely captured the imagination of the Western World. Every one who raised his voice—the Chamber of Commerce, the heads of big corporations as well as the New Dealers and the Progressives—talked about planning something. No doubt they had different ideas of how to plan and what to plan for, but the underlying image dominated most minds. The notion finally reached its grand climax, and its *reductio ad absurdum*, in the vogue of technocracy.
>
> The point I wish to make is that the conception of government as a problem in engineering is a false and misleading conception, that the image of the engineer is not a true image of a statesman, and that society cannot be planned and engineered as if it were a building, a machine, or a ship. The reason why the engineering image is a bad image in politics, a bad working model for political thought, a bad pattern to have in mind when dealing with political issues, is a very simple one. The engineer deals with inanimate materials. The statesman deals with the behavior of persons.
>
> The notion that society can be engineered, planned, fabricated, as if men were inanimate materials, becomes in its extremist manifestations a monstrous blasphemy against life itself.

These statements are a challenge to the engineer's training, his state of mind, and his usefulness to society. That challenge should be accepted and an answer given.

Engineer Can Contribute to Government

Engineers never have been convinced, in great numbers or for long, of the effectiveness of their technique as a main reliance of government. In fact, the clearest, most reasoned, most convincing demonstration of its inapplicability is the work of an engineer. Those interested will find it in an article by David Cushman Coyle entitled "The Twilight of National Planning," published in *Harper's Magazine* for October 1935. In all this we are at one with Mr. Lippmann.

But it will not do to leave the matter in this negative state. The engineer has positive contributions to make to the processes of effective government. He cannot make them unless certain misconceptions expressed in Mr. Lippmann's address are removed and the real nature of his contribution is revealed. There are 2 primary misconceptions: (1) The engineer cannot "dictate to nature." He is the humble disciple of nature, serving society by virtue of that discipleship. (2) His undertakings grow ever farther removed from the completely material realm, and must perforce deal ever more and more with the realization of human ends, whereby the completed structure or mechanism is a joint product of material science on the one hand, and human desires, needs, and possibilities on the other. In no branch of engineering does this appear more clearly than in the modern forms of "scientific management," of which the foundation is a fundamental and sincere comprehension of the human and personal element. Engineering is science applied to human needs. It is both a science and an art. If it is not both, it is not engineering.

Another characteristic of engineering is derived from the fact that it is an applied science. It is science applied to definite purposes; and definition of the purpose becomes the ruling factor in engineering design. In government a similar definition of fundamental purpose is sadly needed. Our national policies are guided by such sec-

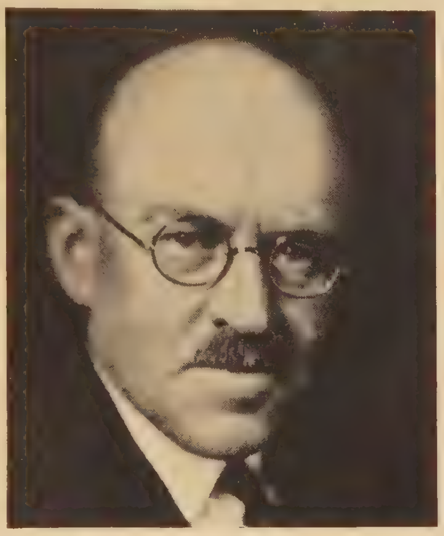
ondary and derivative purposes as raising the price level, restoring the freedom of international trade, raising wages, shortening hours, controlling production, restraining competition. Each of these confidently is put forward as a good in itself, with small pains taken to see that each is related to some larger, general set of purposes.

Good engineering is based upon a careful statement of the problem to be solved; and it happens that our profession has formulated such a statement of the economic problem and has publicly offered it for the consideration of government and governed. It is to be found in the first progress report of the committee on economic balance of American Engineering Council. It reads as follows:

> The problem is "the selection and recommendation of such governmental, financial, and business policies as will maintain in the United States a standard of living that is high, broadly distributed, and free from severe fluctuations."

At first sight such a statement appears trite and sterile; but when we take the trouble to examine the infinitude of partial and conflicting policies that go to make up our total program at this moment, the need becomes clear for some such statement of fundamental purposes, to which all policies must be referred.

A third contribution of our profession—and the last to be suggested in this connection—is a certain knowledge, and a particular faith. The knowledge is that the physical requirements are now at hand for a material standard of living far higher than the human race ever before has enjoyed. There are no physical obstacles. The engineer has removed them. He has played his part. If fault there be, it lies at some other door than this.



Doctor Flanders

With the knowledge goes a faith. He has faith that the complicated social and political problems involved in reaching our objective can be solved—not immediately nor completely, but in such wise and with such speed as may lead to a continuance of our old progress toward a higher and more widely distributed material prosperity. This knowledge and this faith we would share with others.

It is a privilege to belong to a profession that combines the practice of a science and an art. The combination is essential for leadership and achievement. For some time, it has seemed that at least 3 branches of education and professional practice are well fitted to prepare men for life in our present troubled world. They are the doctors, the engineers (to an extent and for reasons I have endeavored to explain), and the graduates of the first-rank schools of business administration, together with the practitioners of business who have attained professional first rank without grace of formal education.

Not only is each of these professions at once a science and an art, but they have another property in common. Each has to face the harsh judgment of ascertainable fact. For the doctor, the patient gets worse or better, lives or dies. For the engineer, the dam endures and serves its economic purposes, or it goes out under the pressure of the flood, scattering death and destruction. The business man faces the grim entries on the balance sheet. Each is in touch with reality. Society needs the touch of reality.

How should all this affect our lives and our actions? In many ways, but principally in 2 ways: We should derive from these considerations a deep and effective sense of the worth of our profession, and likewise of the responsibilities we bear as engineers.

A Current Problem As the Engineer Sees It

It may be worth while to consider one of our current problems in the light of the engineer's knowledge and experience. We believe that the standard of living may be greatly raised for the mass of the population which is able and willing to work. We believe also that the increasing efficiency of machinery, processes, and management will permit the world's work to be done in shorter hours with more leisure for rational enjoyment. In a word we are sympathetic with and committed to the objectives of the present active labor movement in its endeavor to attain shorter hours and higher wages.

But the higher wages must be real wages, that is to say, they must be able to purchase more goods and services for the wage earner and his family. A mere increase in dollar wages will not do if there are no more goods and services to be bought and if prices advance as fast as or faster than wages do. When we see output restricted by shorter hours and the slowing up of the introduction of improved machinery, while wages are being raised, we are justified as engineers in applying elementary analysis to the problem. We must conclude on such analysis that it is hopeless to expect more goods for higher wages if less goods per worker are made. The hope for a better living under those circumstances is illusory and cruelly deceptive.

However, there is hope for a better living, and that better living can come only from better production as a preliminary to better distribution. For that better production—and particularly for better production in shorter hours—the world is now, and in the future will be, dependent on the engineer, as it has been in the past. If our hopes for better material conditions are to be realized, there will be work for the research engineer, for the process engineer, for the designing engineer, for the management engineer. And the sooner this is realized by the pro-

tagonists in our present social strife the better it will be for all concerned.

A Major Threat to Social Progress

It is in our experience and our present method of meeting these current problems that we find the engineer's responsibilities of today. By the pressure of attractive but impossible doctrine, his usefulness to society is threatened; and with the limiting of his usefulness, there is arising a major threat to the social progress we have been making hitherto. We cannot ignore this situation. We must exercise our responsibility more for the sake of society as a whole than for the sake of ourselves as individual engineers or for the private interests of the businesses with which we may be connected.

There is indeed danger in the fact that the material progress with which we are concerned is so closely associated with business interests that they may seem to be one and the same thing. They are not completely so. There is a large area of business as it has been pursued in years past that has not been socially constructive, but socially dangerous instead. Perhaps the largest single area of this harmful business activity has been found in the realm of security speculation and its allied enterprises. Unfortunately for one area of our responsibility, this speculative activity has been so closely associated with the operation of utilities that it is difficult for the general public to distinguish between the useful and socially necessary on the one hand, and the destructive and damnable on the other. A part of our problem lies in making this distinction clear within our own minds and then in presenting the distinction so clearly that we can take the lead as individual engineers in directing public policy on this utilities question into channels more nearly serving the public interest than does the direction now being pursued.

Another danger that we must carefully avoid is that of running wild on the social and economic aspects of our profession and neglecting the technical foundation on which is built everything else that we say and do. The other serious danger, that we may be rash enough to carry our whole engineering point of view over into social planning, has already been discussed.

Whether or not as individuals or as a profession we attain to high reputation or only to humble usefulness, we know that our civilization depends on us. In the words of Spengler, though with more hopeful emphasis:

> The center of this artificial and complicated realm of the machine is the organizer and manager. The mind, not the hand, holds it together. But, for that very reason, to preserve the ever-endangered structure, one figure is even more important than all the energy of enterprising master-men that make cities to grow out of the ground and alter the picture of the landscape; it is a figure that is apt to be forgotten in this conflict of politics—the engineer, the priest of the machine, the man who knows it. Not merely the importance, but the very existence of the industry depends upon the existence of the hundred thousand talented, rigorously schooled brains that command the technique and develop it onward and onward. The quiet engineer it is who is the machine's master and destiny. His thought is as possibility what the machine is as actuality.

Those words are true! As individuals we may struggle, and succeed or fail; we may be rewarded beyond our deserts or miss a recognition that was richly our due. Whatever may happen, this at least we may hold to: that we lived in a glorious age, full of human possibilities; and that our daily work lay at the heart and center of that age.

As to our responsibilities, they are great. Perhaps the greatest of them lies in the understanding of the nature of the mechanisms and of the organizations on which depend the material interests of our generation. It is hard to say whether the greatest danger to them lies in their being perverted and frustrated by powerful selfish interests, or in being overthrown by the recklessness and ignorance of our fellow citizens—even by those moved by the best of intentions. Our material blessings do not come naturally, as fruit grows on a tree. They come because thousands of individuals, having engineering and organizing skill, devote themselves in large and small capacities to keeping the machinery of civilization in running order. It is an inescapable duty that we each make of ourselves centers of education and influence, to the end that our useful offices may continue, and our civilization fulfill its destiny of an ever-growing service to the needs of mankind.

The Engineer's Responsibilities to the Public

Doctor Vannevar Bush has analyzed the social responsibility of the organized engineering profession with particular reference to its relations with government (see article elsewhere in this issue). I am going to suggest the nature of our responsibilities to the general public. We are now engaged in a strenuous race, a race between education and the breakdown of democratic government. As one of its major resulting catastrophies the breakdown of democratic government would destroy the engineer's usefulness to society and put an end to all reasonable hope for a continuation of our old progress toward a higher standard of living for the mass of our fellow citizens. To forestall this disaster, widespread education of the voting public is necessary. The first step in this process is our own self-education. Perhaps we never have stopped to think that we may be in need of that, that some of the ideas we have held since our youth may need revision.

We should examine our beliefs with all the critical capacity at our command. We should study and ponder with open minds proposals to which we have an instinctive aversion. Thomas Nixon Carver once wrote that the trouble with radicals is that they read only radical literature, and the trouble with conservatives is that they read nothing at all. We must erase this stigma from our record and approach these new problems from all directions, furnishing ourselves thereby with opinions perhaps somewhat changed but more solidly founded than before, for we do have new problems and they may require from us new attitudes. It is doubtless true that economic law does not change; neither does physical law. But we discover new physical laws and perhaps we may discover new economic ones. At any rate, we have behind us a marvelous record of new invention and enterprise operat-

ing under the ancient and immutable physical laws. Is it not possible that we may discover workable and useful social novelties operable under the ancient and immutable social laws?

As engineers, it is incumbent upon us to distinguish between the device that flies in the face of nature and the device that makes a new application of natural law. With our own beliefs fresh and clear and in order, we face the task of making them broadly useful. I wish to stress our responsibility as an educational force counteracting the forces of social dissolution. In our national meetings, in the meetings of our local sections, in our personal appearances before other bodies and groups, in our private conversations, in human contacts which we must learn to multiply and elaborate, in every way ingenuity can provide, with all the patience and wisdom at our command, we must speak and work for the continuance of an ordered society that moves forward to higher material possessions, more fruitful leisure, and deeper spiritual achievement.

Perhaps you will forgive me if I close with words that originally were addressed to a graduating class at commencement, for, in a sense, we too are facing a commencement.

In the Declaration of Independence our forefathers demanded for the individual the right to "life, liberty, and the pursuit of happiness." When those words were written it was a new idea in the world that happiness might be attained. The ancients and those of medieval times had other aspirations. They sought honor, liberty, and salvation, and were not sure that happiness was consistent with these or even possible on any terms. May I suggest that there is a deeper, richer word than "happiness," and that is the word, "satisfaction."

It is not too much to hope that we may attain satisfaction in the practice of our profession. In part it will come from the very fortunate fact that many of us as engineers see the idea in the mind finally embodied in the material machine, process, or structure, and actively serving the needs of mankind. But an even more powerful satisfaction will come to us if we see our profession in the aspects of history and of the evolving human drama. For those who see, and who act on the vision, the fullness of life is reserved. May that gift be ours!

The Engineer of Tomorrow

He should be guided, but not limited, by the record of the past

By A. M. MacCUTCHEON
PRESIDENT AIEE 1936-37

DURING this past year I have talked with and consulted many engineers. I have learned of their ideas and their ideals. They are men of purpose and conviction. The engineering record of the last 50 years is astounding; but these men are not satisfied. The typical engineer is more interested in the problems of the future than in the accomplishments of the past. The engineering profession demands that the engineer of tomorrow shall be broader and greater than the engineer of today or yesterday.

How can this be accomplished? None can deny that we are living in a changing world. History is the great teacher. We should be guided, but not limited, by the record of the past. The last hundred years has been a period of engineering invention and development, and invention will never cease. We should endeavor to decide whether the next 25 years is not to be more largely a period of adjustment—of consolidating, co-ordinating, perfecting, and best utilizing the inventions and developments of the past.

Much has been said of the "engineering method" of approach to, and solution of, a problem. Just what is this "engineering method," and has the engineering profession invariably used it in the consideration of its own problems? In an article published in the February 1937 issue of Electrical Engineering (pages 206–07), Morris Leeds, a Fellow of the AIEE, defines the essentials as follows:

> A clear conception and precise statement of the objective to be achieved; a consideration, as thorough as practicable, of all the factors—be they physical, social, or psychological—which will influence or may be employed in getting the desired results; and, on the basis of this knowledge, the formulation of the most effective plan for achieving results that can be developed in the allowable time.

To this I suggest that the following be added:

1. An investigation to develop all facts pertinent to the problem.
2. Recognition of additional information which is necessary, and which may be secured by research and experimentation.
3. Correlation and evaluation of the information gathered. Conflicting evidence often develops, and each item should be weighted in reaching the final decision.
4. The decision shall be uninfluenced by ulterior considerations.

I have believed that engineering is an art almost as

The president's message presented at the opening session of the AIEE summer convention, Milwaukee, Wis., June 21, 1937.

much as it is a science. As an illustration, consider the design of a new electric motor. Assumptions are made as to the conditions to be met when the motor is applied, but exact information as to the operating conditions is seldom available. While the motor is designed for a specific horsepower, practically never is this the exact horsepower demanded of it in service. The proper weighting to be given to efficiency, cost, heating, and dimensions must be decided by the designer. A penalty in one direction is often an advantage in another. Materials are selected with a view to taking advantage of technical progress. Often these materials are yet unproved for the specific purpose. Innumerable decisions must be made, based upon past experience and probability. To be an engineering achievement, the finished motor must be as much a work of art as a painting by a master, and it cannot alone depend on the accurate solving of a number of formulas. The successful designer is guided by a trained instinct as much as by acquired knowledge. Of a hundred possible designs, he selects one in much the same way that the musician develops his creative theme. If this is a correct theory, its recognition is important. The future practice of engineering, the future training of engineers, the future relation of engineers to the rest of industry and society, should be influenced by this theory.

Many problems are referred to the engineer. Though the trained engineer is best qualified to make the decision, his recommendation often is questioned. He is expected, being an engineer, to demonstrate quickly and convincingly that no other solution was possible. Seldom is this true. While no engineer can always be right, this is the limit toward which he strives. The critics of engineers are asked to view the remarkable engineering progress of the last 50 years, and to value engineering opinion accordingly; but the engineers themselves should concentrate on what they have failed to accomplish, and by the application of the "engineering method" improve their engineering.

Applying self-analysis, what may be our faults of the past? Have we ourselves viewed engineering too much as a science and not enough as an art? Have we thought that engineering dealt only with inanimate things and natural forces, and failed to recognize that human reactions and the interests of humanity are essential factors to be considered and properly weighted in any engineering recommendation? Have we been too dictatorial and assumed that others should accept our decisions simply because we are engineers? Have we been too intolerant of criticism and failed to profit thereby? Have we had too great a tendency to refuse to recognize things as they are, and insist on how we think they should be? Have we given full value to the viewpoints of others? Have we always realized that while an exchange of views is desirable, a prolonged argument is seldom convincing? Have we been good students of human psychology and fully developed our ability to win confidence and influence others? Have we always recognized that the best speech is of no value unless it is heard; the best book of no value unless it is read; the best engineering plan of no value unless it is so convincingly presented that it is endorsed and adopted by others? Has the engineering profession always charted its course over a period of years, or has it planned from day to day and month to month?

In a recent talk, I presented this definition of an engineer: "one who through training, study, and practice adapts and controls the materials and forces of nature to the benefit of himself, his fellow engineers, and the rest of the human family." This definition implies the adapting and controlling of men, for they certainly can be classed as among the materials and forces of nature. I believe that society's past conception of engineering has been limited to invention, research, design, and education.

The following I list as the desirable qualities to be possessed by every engineer: integrity, dependability, enthusiasm, vision, determination, resourcefulness, forcefulness, adaptability, co-operation, diplomacy, friendliness, broadmindedness, training, experience, and engineering knowledge. Has every engineer of the past, and does every engineer of the present, meet this or a better definition, and possess all of these qualifications to a high degree? If not, is this possible for the engineer of tomorrow? Should the engineer of tomorrow be controlled by 4 fundamental ideals—co-operation, consideration of others, service, and accomplishment?

For more than 50 years, the American Institute of Electrical Engineers has represented professionally the electrical engineers of America, led by such distinguished engineers as Doctor Elihu Thomson, Doctor Edward Weston, and Doctor E. B. Meyer, all of whom have been lost to us during the past year. Their enthusiasm, their cheerful optimism, their breadth of vision, their indomitable spirit, their engineering ability, form a pattern which the engineer of tomorrow well may emulate. As the engineer of tomorrow learns from, and endeavors to improve upon, the engineer of yesterday, so should the Institute profit by the past and fully meet its opportunity and responsibility in representing the electrical profession in the future. To me it seems that our organization should not be static. As the profession grows and changes, it should grow and change, ever keeping in mind its fundamental purpose. Fine as the record has been in presenting, discussing, and recording technical progress; in developing standardization; in fostering and sponsoring engineering education in co-operation with all other agencies; in working with other engineering societies to develop professional ethics and a sense of professional responsibility; in encouraging acquaintance, and providing opportunity for developing the social instinct, is not still greater achievement possible?

Among the national societies and between the national and local societies, a still closer co-operation is needed. Many of their problems and interests are diverse. Many are closely allied. Their most fundamental purpose—service to the profession and to humanity—is identical. Their work should be further co-ordinated; duplication and conflict should be eliminated, each supplementing the others.

Is it not possible to make the Institute more representative of the whole profession? Cannot the organization develop a still finer program, interesting many who are

not now interested? For example, should there not be more papers and articles recording experience, which would appeal particularly to the many electrical engineers who use electric power and electrical equipment but are not connected with the manufacture of either—papers that would relate to electrical applications in the textile, the automobile, the oil, the chemical, the mining, and other industries? Might there not be an increased consideration of the problems of the profession, such as registration, and an endeavor even more actively to study and assist in their solution? Can there be a movement toward providing meetings and presenting information to those associated with the electrical industry but not eligible for membership in the Institute? Is all possible being done to encourage and develop the young men in the technical schools?

I suggest one additional committee, a committee to investigate, review, and plan for "the future of the AIEE." Their deliberations should consider the next 5, 10, and even 25 years. Would we, today, be satisfied with the Institute as it was in 1912? Will the members in 1962 be content with the 1937 model? Is it not in accordance with the "engineering method" not to accept things as they are if improvement is possible, but to make no change unless improvement is probable? I further suggest that this proposed committee particularly plan for activity in those fields where there is the greatest need, even though not the greatest interest.

The Engineer's Responsibility to Society

A student speaks his mind on a subject of importance to engineers

By CHAS. W. BLAKER
ENROLLED STUDENT AIEE

OF ALL the definitions of engineering that have been propounded, the one that seems to express most clearly and accurately the true function of the engineer is found in the preamble to the constitution of American Engineering Council. In that document engineering is defined as the "science of controlling the forces and utilizing the materials of nature for the benefit of man, and the art of organizing and directing human activities in connection therewith."

Engineering is, indeed, a science. Without the least fear of successful contradiction, engineering might be called the oldest of the sciences. Far back in the gray dawn of civilization were heard the first awakenings of the engineering consciousness. The savage who first learned to utilize the energy of a distorted elastic system in the contrivance of the bow and arrow was an engineer. The primordial man who recognized the power of fire as a protective agent against the prowling terrors of the night was an engineer as truly as any graduate of our foremost technical institutions of today. In the field of science, then, is to be found the generally accepted work of the engineer. Yet, in accord with the definition quoted, scientific application of the laws of nature covers only part of the field of engineering. Associated with the profession there is also the *art* of organizing and directing human activities. Any ordinary layman, if asked to give his interpretation of the term engineering, would no more think of social organization than he would of music. Many engineers even have no awareness of the art involved in their profession. Yet that engineering does involve, inherently, the art of directing human activities in connection with the scientific utilization of natural resources, is a fact that upon a little consideration must be accepted by even the most ardently technical man. That the duty of the engineer to society extends specifically into this field of organization must be apparent to all. The engineer can no more expect the products of his work to be used intelligently by uninitiated society than could a child be expected to use matches and debris for anything other than a harmful conflagration. Yet engineers, as a profession, have been consistently neglecting this most important side of their work, thus making possible the international conflagration of the years 1914 to 1918. This is discussed more in detail later in this article.

If the engineer is to concern himself with society, what is he to understand in the term? It has had many interpretations in the past, but the one that seems to explain it most clearly is the simple term humanity, or human activity, as mentioned in the AEC definition of engineering quoted previously. The engineer's responsibility to society is a humanistic one, involving the understanding of humanity and its individual personal problems as well as an understanding of the scientific problem and its stereotyped solution. It is necessary for the professional man to remember that, before any contemplation of engineering as a profession occupied his mind, he was an individual in a society of individuals; and that, as a matter of course, his duty is first to humanity and next to his

A paper presented at a conference of the AIEE Branches at the University of Pittsburgh, Carnegie Institute of Technology, and University of West Virginia, held at Pittsburgh, Pa., January 12, 1937.

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profession. One might say of engineering, as Lincoln said of government, that in order to survive it must be a profession for, by, and of the people; otherwise it must pass in the manner of governments and institutions from the beginning of time that have violated that simple code.

In a broad sense, the responsibility of the engineer to society may be divided into 3 major branches: (1) conservation, (2) production, and (3) distribution. In the last few years, there has been much publicity concerning the conservation problem. The public has been dosed quite efficiently with conservation propaganda; to such an extent has this been carried out that public sentiment has turned conservation conscious, with the result that much work that is good has been accomplished. Yet much of this fervor is but a transient emotion, engendered by a mild hysteria. Hence, it can but pass, leaving a most incomplete work in its wake, for pure sentiment, though a most potent force in mob psychology, is not sufficiently stable to form a basis upon which may be built the superstructure of any enduring principle. If conservation is a necessity, and in our present condition of envisaged power shortage it certainly is, the engineer should carry out a program of public education that will acquaint the public, in general, with the tremendous scope and importance of the problem.

In contrast to the problem of conservation, that formed by production is of a secondary type, being a problem not in the actual processes of production, but in the complications created by our system of mass production and intense specialization. The production lines in our large automobile factories are typical of the type of production wherein the individual consciousness is submerged in that of the entire group. The conditions of our mines and factories are all pregnant with social problems—with living-together implications, as one writer has called them. It is to the engineer that the people must look for the continuation of their individuality in the maze of industrial unification and the amalgamation of humanity.

Of the 3 problems, conservation, production, and distribution, the last is perhaps the most widely publicized, not only in the United States, but throughout the world. It has become an international problem, the solution of which will involve an eruption and disturbance of all existing principles. This disturbance will involve not a change or revolution in that sense, but an upheaval and purging of existing principles—this rather than radical change because there appears to be no other working economic system wherein the individual is permitted to retain his individuality and is as well rewarded, materially, for individual achievement as in the system under which we in the United States of America live. Every economic system has its faults; but the faults inherent in capitalism, in comparison with those of other working systems are small indeed from a humanistic viewpoint. By that I have no intention of implying that capitalism is nearly fault-free; it is far from that. However, in relation to other economic systems its defects are minor. In the purging mentioned, probably the evils that will be given the most careful attention are those accompanying idle and unmerited wealth. With the disappearance of that type of wealth-holder, and the removal of profit from war, the government will have made a definite advance toward the era of social readjustment and capitalism will be enabled to assume the position it merits. As a clear and analytic thinker is needed, who can be better qualified than the engineer to handle the remedial measures; who more naturally should handle them than the one whose works have created situations necessitating those remedies?

All the foregoing discussion might be condensed into a series of 4 "shifts in the social consciousness" for which the engineer might be proved responsible:

1. Shift from individualism to interdependence.
2. Shift from competition to co-operation.
3. Shift from scarcity to plenty with the accompanying living-together implications of industrialized society.
4. Shift from stressing rights to stressing duties.

A sincere consideration of these shifts will clarify the responsible position of the engineer in connection with the problems he has created.

Last of all to be discussed is that scourge of mankind—War. Not long ago a well-known speaker in Pittsburgh placed the responsibility for the Great War at the feet of the engineer. That is a most startling and grave accusation, the most appalling thing about it being its partial truth. None can deny that war would be impossible were all engineers to decree that it should be made so, for with the engineer lies the power to halt the advancing tide of destruction that threatens to tear apart the familiar structures of civilization. The insupportable horrors of warfare as it is made possible by engineering developments form one of the few immanent causes for the failure of engineering as mentioned earlier in this article. True, he who wages a battle against the protagonists of war fights no puny skirmish, for against his calculation and powers for analytic thinking lies the weight of money, that magic talisman used to open the doors to the material forces of the world. It will be a battle requiring men.

In closing, a few commonplace remedial measures are outlined, in a study of which the engineer might well profit:

1. Legislation for remedy of existing ills.
2. Thoughtful study of governmental alteration without disturbing the fundamentally sound principles of good government.
3. Profit removal from war.
4. Sensible and equitable distribution of national wealth.

Let engineers interest themselves in something outside their narrow technical field for a time—something outside the bounds of science—and become human and humanitarian, for it is only in such an interest that they can possibly find the solution to the myriad problems of adjustment and reparation awaiting them. In the words of Doctor W. F. Durand, president of the Third World Power Conference, held in Washington, D. C., last year: "What we are urging is a quickened sense, on the part of the engineer, of his responsibilities, not alone in a purely professional sense, but as a citizen of his community...of the world."

An Experiment in the Recognition of Engineers

By ROGER I. WILKINSON
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Recognition of outstanding young American electrical engineers by Eta Kappa Nu, honorary electrical engineering society, began with the presentation of awards for 1936. The society expects its plan of annual awards to incite a fuller and broader professional development of young electrical engineers. Statistics for the men nominated for the 1936 awards are presented and discussed in this article.

IMPLICIT in American democracy is the idea that those who accept and discharge the greatest responsibilities, and those who contribute the most exceptional discoveries and inventions, shall be accorded the highest positions in the respect of their fellow citizens. Practically the only restriction placed on a man's activities is that his endeavors should be oriented in accord with mankind's persistent struggles to attain certain inalienable rights. The greatest of these is that he should one way or another forward the general opportunity for the pursuit of happiness. His own reward is presumed to follow axiomatically.

As with all pure theories, because of certain causes not being comprehended exactly, and of fortuitous circumstances, the practical application rarely works out precisely as predicted. Thus it was that the honorary electrical engineering society, Eta Kappa Nu, proposed to lend whatever weight it might to a more perfect operation of the American "democratic theory," at least as far as electrical engineers were concerned. In its establishment in 1936 of the Eta Kappa Nu Recognition of Outstanding Young Electrical Engineers, then, it is not surprising that the preamble to the conditions of award should state that, "As evidenced by their past records and future promise, this recognition shall be given annually to young electrical engineering graduates, for *meritorious service in the interests of their fellow men*." In addition to more nearly assuring that due and appropriate recognitions accrue to outstanding young engineers, the award plan hoped to attain 2 other ends, scarcely less important: (1) to give to the engineering profession concrete examples of what young men under 35 years of age and not more than 10 years out of college can be expected to achieve, and (2) to inspire by these young men's careers, and to furnish guides for, undergraduates and new engineering graduates to take up their own professional development as soon as possible.

Very naturally, a broad range of accomplishments from scientific research to civic and political activity and artistic creation is recognized, so as to encourage young engineers to obtain a truly liberal and humanistic perspective at an early point in their careers. Figure 1 shows the contents of the questionnaire which each outstanding young electrical engineer nominated was asked to return. It will give an idea of the breadth of interests which Eta Kappa Nu feels that an engineer who takes full advantage of his academic and postacademic training might well acquire.

Nominations for the 1936 recognition to the number of 47 were received from all of the groups of persons eligible to propose candidates. The distribution of nominators is shown in table I. It is interesting to note that nominations came from 21 different states of the union, being as widely distributed as Vermont and New Hampshire, Florida, Texas, California, and Oregon, about half lying west of the Mississippi. Because of the preponderant number of nominations by heads of electrical engineering departments, there is a close correlation between the schools attended by the nominees and the states from which the nominations came. The present locations of these 47 accomplished young engineers are, of course, less widely distributed due to the concentration of electrical engineers in the areas of denser population. Quite naturally New Jersey, Pennsylvania, and New York each have over twice as many as any of the other 13 states of business, claiming 6, 9, and 10, respectively. The general types of work and industries in which they are engaged are shown in table II.

Table III gives the distribution of years by which the nominees received their baccalaureate degrees in electrical engineering, and their ages on April 1, 1936. Due to a possible misinterpretation of the wording of the 1936 regulations, the one case of a candidate being 35 years old, that is *over* 35, was not thrown out. In the future, however, only those *less* than 35 years of age will be considered to be eligible. The expected tendency for substantial achievement to be attained as an engineer grows more experienced is well borne out by the heavier concentration of nominees in the 1926 and 1927 graduation years and in the 30 to 34 age classifications.

Table I. Distribution of Nominators

Members or Groups of Members of Eta Kappa Nu	
Individual members	2
Alumni chapters	2
Undergraduate chapters	2
Sections of the American Institute of Electrical Engineers	6
Heads of Electrical Engineering Departments of American Colleges	37
	49
Duplicates	2
Net	47

Written especially for ELECTRICAL ENGINEERING.

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Record of Achievement

Date..................

To the Secretary, Jury of Award
Dear Sir:

The answers to the questions below give, to the best of my knowledge, a factual record of my work and activities since graduation from college.

I. General Information

a. Name..

b. Date of birth.................. *c.* Place of birth..................

d. Home address..

e. Business address..

f. College granting your baccalaureate degree..........................

g. Particular years attended and year graduated..........................

h. Average grade attained in undergraduate work............%............

i. Social fraternity and honor societies of which you are a member..........

j. Married?..............Date..............Children and ages..........

k. Do you rent or own your own home?..............................

l. Attach in the space below a small photograph or snapshot of yourself.

II. "On the Job" Record

a. By what companies or institutions have you been employed and in what capacities since graduation? Salaries at start and finish of each?

b. What papers have you published as a result of your everyday work, or allied work? (Attach copies if possible.)

c. What new and important facts have you discovered?

d. What new machines, methods, theories have you devised? Patents?

e. What application of engineering principles have you made to industrial and business planning or organization?

f. What application of engineering principles have you made to civic problems?

g. What have you done in the instructional field?

h. Have you taken any advanced scientific or professional engineering degrees?

i. What other accomplishments in your job?

III. Record of Activities in Behalf of the Community, State, and Nation

a. What philanthropic work have you actively engaged in?

b. What have you done for the church?

c. Have you led or assisted in boy scout, Y.M.C.A., or other young peoples' organizations?

d. What municipal, state, or other political or social volunteer boards have you served upon?

e. How have you helped further adult education in the community?

f. What have you done to make the depression less heavy for others?

g. Have you actively supported any candidates in political campaigns?

h. Have you ever run for political office yourself?

i. In what way do you think your work under II has added, or will add, to the comfort or happiness of mankind?

IV. Cultural and Aesthetic Development

a. What general (nonengineering) articles or reviews have you written?

b. Since graduation have you attended courses in history, sociology, economics, psychology, to increase your understanding of the social order, and what can be done about it? Additional degrees received?

c. Have you studied one of the fine arts, or attended courses in art appreciation? Degrees or honors received?

b. Have you participated in literary, dramatic, musical, painting, or other fine arts creation? What evidences?

e. Have you made outstanding architectural contributions, or achieved noteworthy results in industrial design or decoration?

f. Have you assisted and encouraged others in developing their cultural potentialities?

g. What books have you read in the last 5 years?

V. Other Accomplishments

a. Have you a hobby? What have you done with it?

b. Do you have any athletic distinctions?

c. What other advanced study have you taken up? Physics? Chemistry? Law? Philosophy? Astronomy? Religion?

d. What engineering societies do you belong to? Offices held?

e. What other organizations do you belong to? Offices held?

f. What else do you do in your spare time?

g. Describe any other accomplishments or honors received.

* * * * *

In addition I refer the jury of selection to the following persons (not less than 3 nor more than 5) who are intimately acquainted with my work and activities. (Please note affiliation, if any, with each person.)

Signed..............................

Figure 1. Questionnaire sent to nominees

At the award dinner given in New York during the winter convention of the AIEE in January 1937, remark was made that the names of the men receiving the award and the 4 honorable mentions hardly sounded like the "Smiths and the Joneses" commonly associated with American progress. The future only can tell whether the ratio will be maintained which resulted in 1936, when of 4 foreign-born nominees 2 were chosen for honors, while only 3 were similarly selected from 43 American-born candidates! It should be stated here, perhaps, that of the remaining men (whose names have not been published) there was a quite sufficient number of "common" names to gratify even the most nationally minded critic.

Further consideration of vital statistics reveals that 70 per cent of the nominees were married, and of these 2 men out of 3 already have one or more children. Relatively few, however, have attained that state of financial security where they own their own home.

The salaries of these men have apparently been very markedly influenced by the depression. The median annual salary by number of years after graduation is shown in table IV. In figure 2 these salaries have been superposed on the curves determined in 4 salary surveys of electrical engineers made in the period from 1923 to 1930. Two were studies by Eta Kappa Nu on its own alumni,[1] the third by the Society for the Promotion of Engineering Education in 1924 on all electrical engineering graduates,[2] and the fourth from a survey in 1928 of graduates of land-grant colleges made by the United States Office of Education.[3]

Other things being equal, one would feel justified in expecting that these exceptional young engineers would equal if not exceed the median salaries of the corresponding Eta Kappa Nu alumni. The recent financial unpleasant-

1. Results of the 1923 study appear in *The Bridge of Eta Kappa Nu* for November 1923, and January and May 1924. Note that averages, *not* medians, were used here. The 1930 study is summarized in "Comparison of Engineers' Salaries in 5 Major Industries," by M. S. Mason and J. A. Umhoefer, *The Bridge*, February 1931; a similar summary by the same authors appears in the *Proceedings* of SPEE, volume 39, 1931, pages 723–39.

2. The SPEE study on electrical engineers was published as Bulletin No. 8 of the Investigation of Engineering Education, volume I, pages 368–87. Also, in *The Bridge* for May 1926, H. P. Hammond compares the SPEE and the HKN 1923 salary results in "The Contributions of Eta Kappa Nu to the Investigation of Engineering Education."

3. "Engineering Graduates of Land Grant Colleges and Universities," by D. S. Bridgman, SPEE *Proceedings*, volume 39, 1931, pages 861–8, sets forth the data collected by the United States Office of Education in 1928 on electrical engineering graduates from 4 typical land-grant institutions.

Table II. Distribution by Types of Work and Industries

Type of Industry	Type of Work: Administration	Operating	Engineering Development	Research	Instructing	Total
Public utilities	●	◐	●●●●●◐	●●		9
Electrical manufacturing	●●◐◐◐		●●●●●● ●●◐◐◐◐ ◐◐◐◐	●●●●◐◐ ◐◐◐◐◐◐	◐	24
Other industries	●		●			2
Educational institutions				●●●●◐◐	●●●●◐◐	10
Government—municipal	◐	◐	●			2
Total	6	1	19½	15	5½	47

● Full time ◐ Part time (assumed half time)

ness, however, has seemingly delayed progress of these engineers, taken as a group, from 2 to 3 years. Somewhat more difficult to explain is the fact that the median of 32 of their starting salaries (nearly all prior to 1929) is only $1,287, lower indeed than those of any of the other studies on figure 2. A partial explanation may be found in the fact that such a preponderant number of the nominees went initially with large electrical manufacturing concerns (see table II). The 1930 Eta Kappa Nu salary study showed this group as receiving the lowest starting salaries, although 10 years later they had caught up with the general average, and thereafter exceeded it.

The problem of evaluating the achievements of so many engineers with such varied interests and activities caused the award organization committee much thought and reflection. The solution seemed to lie somewhere between a consideration of what engineers had probably done and what more they might be doing. After about a year was spent in discussing this basis with numerous leading educators and engineering executives who expressed a considerable interest in the idea, it was finally decided to inaugurate the plan giving a certain weight to nearly every activity a man might have engaged in under the following headings:

(*a*) His achievements of note in his chosen work.
(*b*) What he has done for his community, state or nation.
(*c*) How he has shown his cultural or aesthetic development.
(*d*) His activities in technical societies, and miscellaneous accomplishments, such as athletics, special honors, etc.

The exact weights which were placed on these categories were not decided upon until after reviewing a considerable number of nominees' records, because it was difficult to predict to what extent a group of young engineers might have participated in these various directions. The final weighting suggested by the award organization committee* and accepted for use by the final jury of award was

(*a*)—5 (*b*)—2 (*c*)—1 (*d*)—2

A very careful summary of each man's accomplishment was first made by 2 Eta Kappa Nu committees, and the engineers placed in 3 groups, called *A*, *B*, and *C*, in order to lighten the labor of the jury of award.** Each member of the jury reviewed carefully every one of the 25 nominees who had been placed in the *A* division, while at least one member reported on each of the nominees in the *B* and *C* divisions. Then a comparison of scores rather quickly brought the list down to a relatively small number of eligibles for the recognition honor. After considerable discussion and comparison, the jury selected Frank M. Starr (A'30, University of Colorado, '28) of the General Electric Company at Schenectady, N. Y., to be the first recipient of the Eta Kappa Nu Recognition for Outstanding Young Electrical Engineers. Awards of honorable mention also were given to P. L. Bellaschi (A'29, M'34), E. W. Boehne (A'29), A. C. Seletzky (A'29, M'35), and C. G. Veinott (A'28, M'34).†

Since not all nominees were rated by all members of the jury, it is not practicable to summarize statistically their conclusions—even were it desirable to do so. However, prior to the final jury selections, a fairly detailed analysis of all candidates was made by a committee of Eta Kappa Nu engineers actively interested in the recognition plan, the results of which later tallied very closely with the selections made by the jury of award. A portion of this study covering the 43 of the 47 who returned questionnaires and on whom sufficient information was known for forming relatively reliable ratings is shown in table V. These results, although perhaps not bearing too close analysis quantitatively, are nevertheless thought to be sufficiently revealing qualitatively to indicate quite clearly

Table III. Age and Year of Graduation

Age	Year of Graduation (Bachelor of Science Degree): 1926	1927	1928	1929	1930	1931	1934	Total
26					1		1	2
27						1		1
28			1	1				2
29	1*		3		2			6
30	2	4	1	1				8
31	4	1	1					6
32	4	2	1		1			8
33	4	3		1				8
34	3	1						4
35		1						1
Unknown				1				1
Total	18	12	7	4	4	1	1	47

* Class of 1926; did not graduate.

* The president of Eta Kappa Nu in the fall of 1935 appointed an award organization committee of R. I. Wilkinson (A'35), *chairman*, O. W. Eshbach (A'17, M'30), E. S. Lee (A'20, F'30, director), H. H. Henline (A'19, M'26, national secretary), and C. A. Faust (A'35) to put the recognition plan into effect.

** The jury of award is appointed annually by the president of Eta Kappa Nu and consists of 2 present or past national officers of Eta Kappa Nu, and 3 or more prominent American educators or industrialists. For 1936 L. W. W. Morrow (A'13, F'25, director), C. A. Butcher (M'22), the late General R. I. Rees, and the late E. B. Meyer (A'05, F'27, past-president) were appointed to serve on the jury; E. S. Lee and R. I. Wilkinson filled the 2 appointments from Eta Kappa Nu ranks.

† Of these 5 men, only one attended a college with a chapter of Eta Kappa Nu; later one other became an associate member of the society.

Table IV. Annual Salaries

Number of Years After Graduation	Number of Cases	Annual Salaries in 1936		
		Median	Lowest	Highest
0*	32*	1,287*	938*	2,600*
5	1	2,400		
6	2	2,704		
7	2	2,880		
8	7	3,300	1,900	4,800
9	10	3,210	2,400	8,200
10	15	3,450	2,250	5,600

* These are starting salaries at whatever year of graduation.

certain characteristics of the most exceptional young American electrical engineers who could be discovered in 1936. It is believed that this is the first of this type of comprehensive study of engineers attempted in this country.

In the first place, it is clear from table V that the nominators selected their candidates mainly by their technical accomplishments. Since this category is given the weight of "5," such a basis of selection would seem to have considerable justification. In several instances, however, those with records of the very highest quality of research work or other scientific contributions ranked near the bottom of one or more of the other classifications, thus drastically bringing down their over-all ratings. The fact that only 11 tallies out of 129 under headings *b*, *c*, and *d* exceeded a "50" rating might mean that either the method of appraisal was too severe, or that the engineers had not entered to any extended degree on pursuits outside of their chosen lifetime occupations. Even in the former event, the wide dispersion of the rankings would indicate that many of these technically proficient engineers had not paid very particular attention to their full professional development.

Correlation studies on the association between the various groups of activities showed positive results in every instance.* Only really significant, however, were the *ac*, *bc*, *bd*, and *cd* coefficients of correlation, ranging from $r = 0.34$ to 0.49. That is to say, although those engineers who participated most extensively in civic and social affairs were but little more distinguished technically than those who did not, their concurrent cultural and miscellaneous outside activities were very much greater. It is a little surprising that degree of technical accomplishment and cultural development (*ac*) should be found so strongly associated while no similar connection was noted between, for instance, technical accomplishment and civic and social work or miscellaneous activities. A most tentative hypothesis which might be advanced to comprehend these observed relationships is that a considerable block of the men with the highest technical achievement had concentrated on their personal advancement and development to the neglect of assuming group responsibilities.

Some have argued that in the early years of his professional career an engineer is, and ought to be, too busy on his technical development to devote much of his energy to other activities. The present study of exceptional young engineers disputes such a view, indicating instead a slight superiority of technical achievement by those with considerable extracurricular activity. Partial-correlation studies also show for those engineers in the upper half of the rankings for social and civic activity, a marked association between technical achievement and cultural development. Thus, as far as these facts go, they would seem to suggest that exceptional performance in scientific pursuits need not at all preclude a paralleling development along social and cultural lines.

Just such beliefs that an engineer's "service to mankind is manifested not only by achievements in purely technical pursuits but in a variety of other ways," and that "an education based upon the acquisition of technical knowledge and the development of logical methods of thinking should fit the engineer to achieve substantial success in many lines of endeavor," prompted Eta Kappa Nu to establish the recognition plan.

When it is considered, that, in the main, electrical engineers are working in large business organizations where their technical opportunities are largely prescribed by their immediate or distant superiors, the remaining activities in which a man engages, most of them voluntarily, are likely to be a considerably more accurate clue than his technical proficiency to his value as a citizen. Table V would seem to bolster the claim often heard these days that engineers have not yet gone very far as a professional group in engaging in more than their narrow technical pursuits.

For the purposes of the Eta Kappa Nu recognition, the rating plan was so devised that an engineer cannot be entirely one-sided and reach the top, nor hardly can he be a "jack of all trades and master of none." A study of the careers of the 5 men selected for honors in the first year of the award will quickly confirm the operation of this design. Biographies in some detail of these men appeared in the January 1937 issue of the Eta Kappa Nu *Bridge*, and somewhat briefer summaries covering their technical achievements were reported in the January 1937

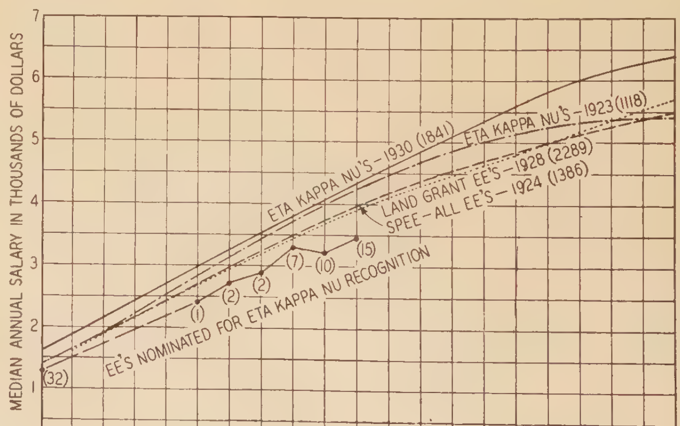

Figure 2. Comparison of salaries

Figures in parenthesis show number of returns

* Although the number of "observations" is only 43, still the fact that they are very homogeneous data seems to permit a certain amount of statistical analysis.

issue of ELECTRICAL ENGINEERING. The addresses made by these men at the award dinner, and which in the main gave their views on young engineers, their success and proper attitudes on life, appear in subsequent issues of the *Bridge*. The merest outline of the activities of Frank Starr, the 1936 recognition winner, will indicate the extent to which a young engineer may be expected to enter upon both technical and "extracurricular" work in his first 10 years after graduation:

(*a*) He is the author of 8 technical papers, several presented before AIEE conventions, principally on the theory and practice of electric power distribution. In 1932 he was awarded the Alfred Noble prize of the ASCE for his paper on "Equivalent Circuits." More recently he has been sent by the General Electric Company on a speaking tour of the country, touching practically every city of 100,000 population, discussing design problems with operating and engineering forces of power companies. His papers are used as texts in a number of engineering schools. He holds 2 patents on the control and protection of a-c network distribution systems, with others pending. He has been a lecturer in the advanced course of the General Electric Company for 6 years.

(*b*) He is a member of the Unitarian Church and the Schenectady Y.M.C.A., and has been active in boy-scout work.

(*c*) He has written a number of human interest articles and personal essays; since graduation he has attended classes in economics, psychology, sales analysis, and public speaking; he is an accomplished speaker; he has studied music and harmony, and is accumulating a sizable phonographic library of symphonic and operatic recordings. He is a member of the Schenectady Civic Players Association and has portrayed rôles in several of their amateur productions. He collects rare editions of books, and has read some 230 substantial books in the last 5 years. His main interest is in philosophy, and he follows a systematic reading plan.

(*d*) He is a member of the AIEE and Edison Golf Club, and is listed in "America's Young Men."

The winner of the Eta Kappa Nu recognition receives no monetary prize; presumably he has been successful

Table V. Rating of Various Activities of 43 Young Engineers

	Type of Activity			
	(a)	(b)	(c)	(d)
Ratings	"On the Job"	Civic and Social	Cultural Development	Technical Societies, Athletic, Miscellaneous
100 (98)	1			
95	4			
90	14			
85	8			1
80	4			1
75	4			
70	3			
65	3			
60		2	1	4
55	1		1	1
50	1	1	4	3
45		4		2
40		3	1	3
35		1	3	2
30		4	5	1
25		1	8	5
20		2	2	7
15		6	4	1
10		7	6	7
5		8	4	3
0		4	4	2
Total	43	43	43	43

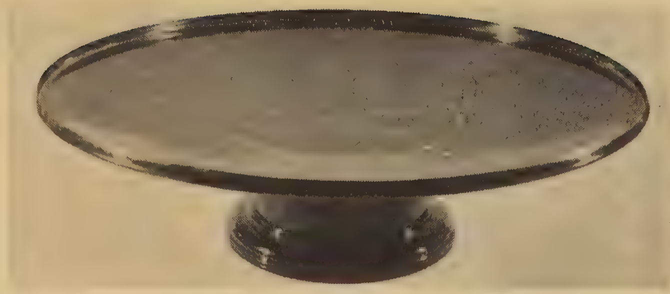

Figure 3. The bowl for the recognition

enough that he is hardly in any particular financial need. Rather it was believed that through the careful and scrupulous recognition of a closely limited number of candidates each year, the honor of being selected would be very great, and that as time proceeds its importance will be advanced by the illustrious records of past successful candidates. A large bronze bowl (figure 3) has been subscribed by some 30 Eta Kappa Nu alumni which will remain on permanent display in the AIEE headquarters in the Engineering Societies Building in New York, and each year will have added to its face the name of the recognition winner. The man, or men, so honored will also be presented with a smaller replica of the large bowl. Recipients of honorable mention are presented with a certificate appropriately naming their chief contributions to science and the humanities.

The future success of the Eta Kappa Nu recognition depends in no small measure on the continuing interest of engineering educators in nominating those young electrical engineers whom they believe to be outstanding. The possibility of doing some exceptionally talented young man a good turn, too, may conceivably persuade the faculties of some of our schools to follow more closely the progress of their graduates. It is apparent that in many instances this is being carefully done today; with the growing development of college personnel officers even closer contacts with the alumni may be expected to be maintained.

No less generous has been the response of the hundreds of business and engineering executives who were asked in the capacity of "references" to give their opinions of the qualifications of the nominees in the 4 major categories outlined hereinbefore. In numerous instances presidents and vice-presidents of the companies employing the nominees responded in considerable detail, often adding a personal word of recommendation. Whether or not he receives formal recognition from Eta Kappa Nu, any man nominated can hardly help but benefit from thus being advantageously called to the attention of those higher in his company or organization.

For 1937 the plan has been altered but very slightly. An interesting observation will be whether the scheme has to a detectable degree impelled any of the 1936 nominees who are still eligible for recognition (and are considered to be automatically renominated) to engage more widely in activities suggested by filling out the 1936 questionnaire. Such will be the severest test of the recognition plan.

Industrial Unit Heaters Cool Transformers

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Unit heaters of the industrial type have been applied for external cooling of transformers and found to be especially useful as a substitute for the original water cooling system or as a supplement to the regular cooling system. Portable substations of smaller size and reduced weight were made possible by the use of these units.

CHOICE of type of transformers, either self-cooled or water-cooled, in the design of a station is usually a matter of economics. In general, where transformers are small or where cooling water is not available, self-cooled transformers are used; where large transformers are required and water is available, water-cooled transformers are selected. Sometimes, however, conditions change through the years and it becomes desirable or necessary to change a water-cooled transformer to a self- or aircooled type.

Having in mind several stations on the Duke power system where cooling systems would soon require extensive replacement, company engineers made an effort in 1930 to apply external coolers to a transformer. A 1,000-kva 44-kv unit was selected and 2 automobile radiators were connected so that the oil would circulate through them from the top to the bottom of the transformer. Large fans forced air through the radiator fins. The results of this test were not encouraging; and from subsequent tests it was evident that the radiators were too small and that natural convection would not give rapid enough circulation through the radiators and piping.

In the latter part of 1933, the cooling coil in a 1,200-kw transformer at Gaston Shoals plant failed inside the tank. Ordinarily the repair or replacement of such a coil would be a minor job, but not so in this instance. This plant was erected about 1906, and was acquired by the Duke company in recent years. There were 9 1,200-kw transformers installed in a small room having thick stone walls and concrete roof. During the early existence of this plant, apprehension was felt that the transformers might be flooded during periods of high water, and therefore they were jacked up 8 feet and a concrete pier erected under each bank. This brought the tops of the transformers close to the 12-inch concrete roof. In these transformers the core and coil assembly and the cooling coils are suspended from the transformer covers. Therefore, to get at this particular cooling coil would require jacking 2 transformers off their piers and removing a portion of the station wall. It was decided to make an attempt to cool this transformer externally, this time using 2 industrial unit heaters as radiators. The particular units chosen were made of cast aluminum and had a fan mounted directly behind the radiating fins. The oil passed straight through the unit through rather large passages. A small pump circulated the oil from the top of the transformer through the coolers and into the bottom of the transformer tank, as shown in figure 1. Although these 2 units did not provide sufficient cooling to keep the temperature of the top oil within desired limits, the results were quite encouraging, so 2 additional unit heaters were obtained and installed, giving the desired results. This installation is shown in figure 2.

It was observed that with these 4 units in operation the fins of the radiators were cold; in other words, heat was not being transferred as rapidly from the oil to the metal of the radiator as from radiator to air. A study was then made of various types of available unit heaters, and one was found which had small copper tubes having a reverse bend. The intimate contact between oil and the walls of the small tubes, together with the comparatively long path obtained by means of the reverse bend, was believed to make a more efficient cooling unit for this application. One such unit was purchased and installed alongside the 4 cast-aluminum heaters, and on test it dissipated heat at approximately the same rate as the 4 cast-aluminum heaters combined. This test gave a

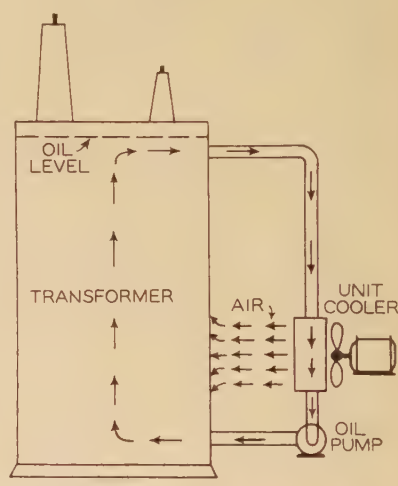

Figure 1. Circulation of oil through cooler and direction of air flow

Figure 2 (below). Cast-aluminum coolers at Gaston Shoals plant

A paper presented before the AIEE North Carolina Section, February 18, 1937.

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fairly accurate idea of the rate of heat dissipation for this unit. All 5 units have been in service since installation.

The next application of these external coolers was at the Greenville substation. Here, as the result of the combination of loss of efficiency of the cooling coils and severe operating conditions, 2 3,500-kva 100-kv transformers operated at unduly high temperatures. To supplement the existing cooling system, 2 coolers were installed on each transformer, together with a small oil-circulating pump for each pair of coolers. This installation gave entirely satisfactory results. A drop of approximately 15 degrees centigrade in the temperature of the top oil was obtained. On this installation a rate of oil circulation giving a drop of 5 degrees centigrade through the cooler with the top oil at 65 degrees and an ambient temperature of 30 degrees was determined upon. This gave good results and has been used on all subsequent installations.

At the Lakewood station, 12 4,000-kva 100-kv transformers are in service. These transformers, manufactured at the end of the World War when there was a shortage of copper, were equipped with iron cooling coils. That the cooling coils as well as other portions of the cooling system would soon have to be replaced was realized several years ago, and one suggestion was that the transformers be made self-cooled by the application of standard transformer radiators. However, when the manufacturers submitted a price of approximately \$50,000, plus an estimated cost of \$10,000 for installation expense, this idea was abandoned. In 1935, a test installation of unit coolers was made on 2 transformers, and complete and accurate data were obtained on cooling them without water in the cooling coils. These tests indicated that, with normal load, as shown by figure 6, 4 coolers per transformer would properly cool them; and it was further observed that spraying sufficient water on the radia-

Figure 5. Copper-tube cooler installed at Gaston Shoals for comparative test with cast - aluminum coolers

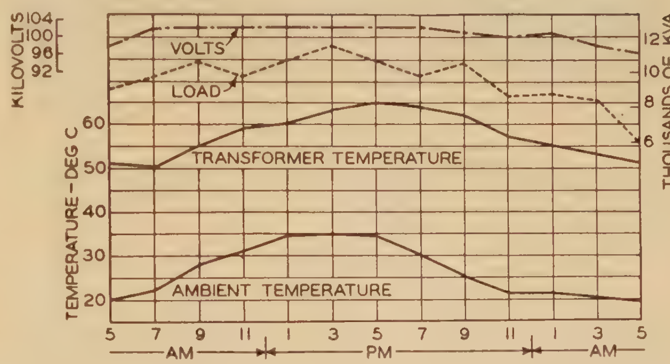


Figure 6. Chart showing 24-hour test on 4,000-kva transformer, using 3 coolers and water spray

Kilovolt-amperes in terms of load on bank of 3 transformers

tor fins to keep them wet increased the rate of heat dissipation to such an extent that only 3 coolers per transformer would be required.

Early in 1936, the cooling reservoir at this station was lost when the dam was washed away. The decision was then made that installing unit coolers on the transformers would cost less than rebuilding the dam. Three coolers per transformer were installed with provision for future installation of a fourth unit should it be found desirable. Two oil circulating pumps per transformer were used.

After the coolers were installed in 1936, various methods of spraying the cooling fins were tried and finally a hollow hub was installed on the fan shaft, which would throw the water radially between the fan and the radiator, and this was found to wet the radiator uniformly with a minimum wastage of water. These hubs were installed on all of the units and properly piped to the city water supply. This spray system gives a reserve to the cooling system which can be used in extremely hot weather or during periods of abnormal load on the transformers. The total cost of labor and material on this installation was under \$10,000.

Recently, 3 transformers were moved from Lakewood and installed at China Grove. A fourth cooler was added on each transformer because no water is available at this station for spraying the fins.

Since the Lakewood installation was made, installations have been made on a 1,000-kva transformer to replace old radiators, on 3 1,000-kva transformers to replace

Figure 3. Details of cast-aluminum coolers

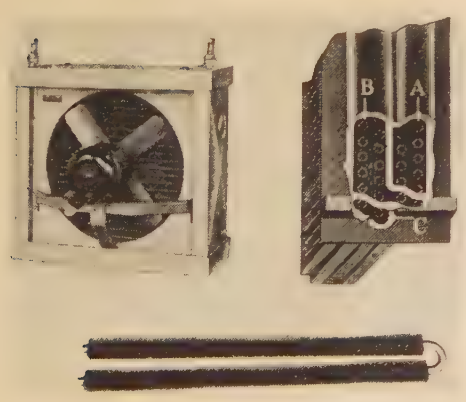
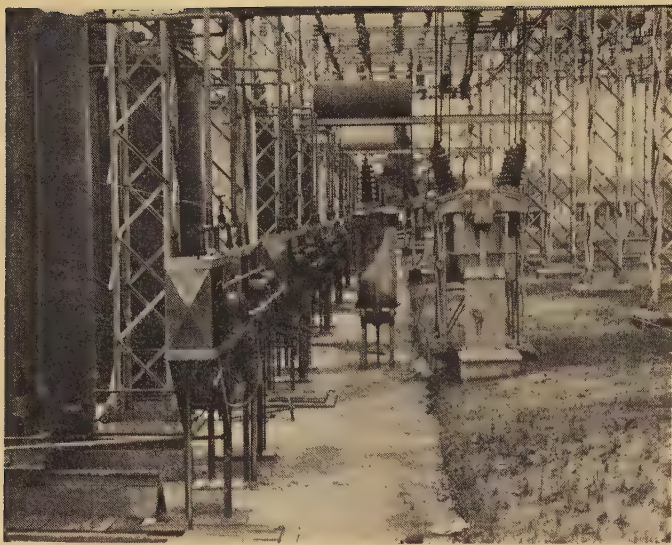


Figure 4. Details of coolers having copper tubes with a reverse bend



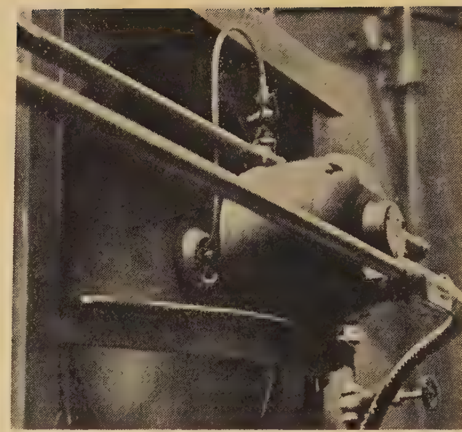


Figure 7. (left) Coolers at Lakewood station

Figure 8. (right) Cooling unit equipped with spray hub

an old water cooling system, and on 3 more 3,500-kva transformers at Greenville to supplement the water cooling system.

A very interesting application is the recent furnishing of 2 1,320-kva portable substations, each equipped with 2 of these coolers by the transformer manufacturer. Not only are these transformer units more compact than those previously furnished, but they also weigh 2,000 pounds less, which is of considerable importance. The importance of keeping the weight of these portable transformers to a minimum can be appreciated when it is realized that these units, 6 in number, are used for backing over 380 banks of transformers having primary voltages of 44, 33, 22, or 13 kv, and secondary voltages of 13.2 kv, 6.6 kv, 2,400 volts, or 600 volts. Many of these are installed in substations located on very poor roads. It is interesting to note that a bank of 3 single-phase self-cooled 55-degree-centigrade transformers to give a capacity of 1,320 kva would weigh approximately 25,500 pounds. By the use of external fans, this weight might be reduced to approximately 21,100 pounds. A standard 3-phase transformer, complete with external fans, would weigh approximately 16,000 pounds. A special portable transformer with tubular radiators, built some time ago, weighs 15,000 pounds plus 6,400 pounds for the trailer, giving a total weight of 21,400 pounds.

The new portable transformer, shown in figure 10, equipped with unit coolers, weighs 13,000 pounds plus 3,000 pounds for the semitrailer, making a total weight of 16,000 pounds. This can be handled readily over almost any road.

The use of external coolers on transformers is not new, but the application of comparatively inexpensive commercial heating units as coolers seems to be an innovation. The principal use would appear to be the substitution in certain instances of this type of cooling for existing water cooling. It also provides a simple and inexpensive method of supplementing existing cooling systems. However, it would probably be wise to consult the transformer manufacturer before making a major change such as replacing an existing cooling system. On new transformers, the most obvious application is on those having space and weight limitations, and on those installed at points where water is not available.

The energy loss of this system is comparable to that of a water cooling system. It is evident that in many instances the first cost and maintenance will be less than with a water cooling system, particularly where reservoirs, cooling towers, or extensive piping systems would be required.

The authors have been informed that the manufacturer of this type of unit cooler, in co-operation with a large electrical manufacturer, has redesigned the unit, using nonrusting parts and improved joints, for this particular application.

Figure 9. Coolers installed on 3 1,000-kva transformers

Figure 10. Portable transformer equipped with 2 coolers

Heat Transfer Efficiency of Range Units

By W. JAMES WALSH
ENROLLED STUDENT AIEE

Surface units of electric ranges have various efficiencies of heat transfer according to the design of the unit. Results of a study made with bright- and black-bottomed utensils are reported in this prize-winning student paper.

THE SUPERIORITY of electric cookery from the standpoint of cleanliness, convenience, and safety has been generally well established. However, the economy of using electricity for cooking depends usually upon 2 factors: (1) the cost of electrical energy, and (2) the efficiency of the equipment employed in utilizing the electrical energy. The results of efficiency tests performed on the surface units of several late-model electric ranges reported in this paper clearly show that there is need for material improvement in the heat transfer efficiency of these units. Since electrical energy can be converted to heat energy with an efficiency of 100 per cent, it is obvious that efficiencies ranging between 50 and 68 per cent, the values found for modern units, are far too low.

The methods employed in determining the heat transfer efficiency of the several units, the results obtained, and several suggestions for possible improvement are presented in this paper.

Selection of Units for Test

Since it was desired to conduct the proposed tests on the selected surface units with the units mounted in the ranges for which they had been designed and as they would be used in actual practice, it was decided to obtain 3 complete, late-model, electric ranges for which the popular demand had been greatest. When the selected ranges were delivered, it was found that but 4 of the 12 surface units furnished with the ranges were of the same wattage. Fortunately, however, 4 different types of surface units were exemplified by the 4 units having the same rating of 1,200 watts. It was therefore decided to perform the proposed tests on these 4 units. The units selected for test are shown in figure 1. For purposes of identification, the units have been labeled, as indicated in figure 1, *A*, *B*, *C*, and *D*, and will be referred to by these symbols.

Measurement of Energy Input to Test Units

In any efficiency test, it is necessary to determine the energy input to the energy-converting device, and the corresponding energy output. In this case, determination of the energy input to the surface units under test, because of the ease and accuracy with which electrical energy may be measured, presented little difficulty, it being merely necessary to select a suitable type of watt-hour meter. The meter selected for use in these tests was a standard instrument of the rotating type commonly used in the calibration of ordinary watt-hour meters. Prior to its use in the tests, the rotating standard was checked for accuracy against a laboratory standard watt-meter and stop watch.

The heat energy equivalent of the electrical input to the units, in calories, is, of course, simply the number of revolutions completed by the disk of the rotating standard multiplied by a suitable constant. However, the standard watt-hour meter was so connected that it not only measured the energy input to the unit under test, but also measured the energy consumed in its own potential circuit and that consumed in the voltmeter employed in measuring the constant alternating voltage applied to the terminals of the unit. The energy consumed in the potential circuit of the watt-hour meter was found to be negligible, but that consumed by the voltmeter was appreciable, so that a correction for it was deemed necessary. It may also be noted that the voltage applied to the units under test

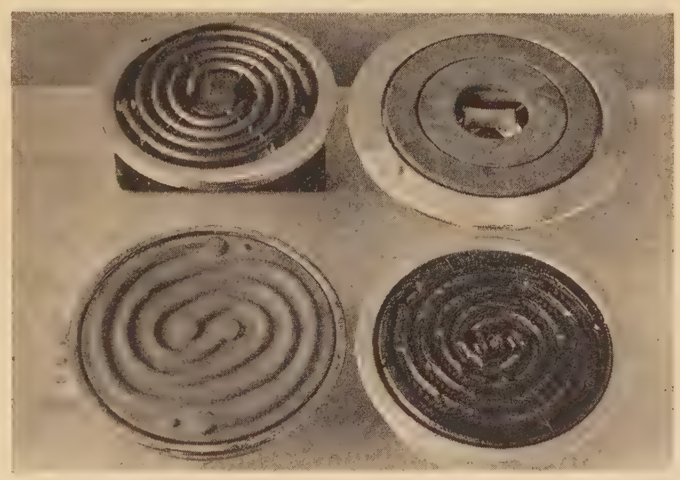


Figure 1. Four types of 1,200-watt units tested

Upper left—Unit *A* Upper right—Unit *B* Lower left—Unit *C* Lower right—Unit *D*

A paper presented at a joint meeting of the Portland Section and the Oregon State College Branch, Corvallis, Ore., May 16, 1936, and subsequently awarded the Institute's 1936 Branch paper prize; recommended for publication by the AIEE committee on award of Institute prizes. Manuscript submitted February 15, 1937; released for publication June 10, 1937.

The author is indebted to the General Electric Company, the Westinghouse Electric & Manufacturing Company, and the Malleable Iron Range Company for the use of the electric ranges and elements studied in this investigation. Lee Bennett of the Mountain States Power Company was actively interested in the project and assisted in securing the equipment for test. The utensils used were furnished by the Aluminum Company of America. Much valuable assistance in conducting the tests was rendered by W. Arno Gish and Charles H. Butler. The author would also like to express his appreciation to Professor F. O. McMillan of the electrical engineering department of Oregon State College who suggested the subject and offered many valuable and helpful suggestions throughout the investigation.

was measured at the terminals of the units, so that no correction for losses occurring in the range wiring needed to be applied to the watt-hour meter reading.

The energy input to the unit under test at time t seconds from the start of the test may then, taking into account the energy consumed by the voltmeter, be expressed as follows:

$$W_t = 860.4\left(K_h R - \frac{E^2 t}{3{,}600 r}\right) \tag{1}$$

in which W_t is the energy input to the unit in calories, K_h is the disk constant of the watt-hour meter in watt-hours per revolution, R is the number of revolutions completed by the disk of the watt-hour meter in the t seconds which have elapsed since the start of the test, E is the effective value of the alternating voltage maintained constantly at the terminals of the unit, r is the resistance of the voltmeter in ohms, and t, as previously indicated, is the time in seconds which have elapsed since the test was started.

Determination of Energy Transferred by Surface Units

While the determination of the energy input to the surface units was found to be a very simple matter, the measurement of the corresponding useful energy transferred by the unit was, in comparison at least, a much more difficult problem. Several methods of determining this essential quantity were considered. One of these entailed the use of a mass of some metal such as copper or iron with the use of thermocouples as the temperature-measuring device. It was decided, however, that the tests would be much more representative if a water-filled utensil of a type ordinarily used on the units in practice was employed. This further had the added value of presenting temperature differences between the unit and the substance being heated more commonly encountered in actual practice.

The suitability of several liquids other than water as the liquid to be heated was also investigated. The few liquids having suitable characteristics, however, either proved too costly, were not readily available, or information concerning the behavior of their specific heats over the temperature range to be covered was either very uncertain or apparently nonexistent.

Figure 2. Aluminum pans used in the tests

Having decided that an ordinary kitchen utensil filled with water would be used as the receiver of the useful energy transferred by the units under test, there remained other items to be considered, such as the type of utensil to be used, and the means to be employed in measuring the temperature of the water. Since aluminum utensils have been widely used in recent years, 2 2-quart vessels of that material were selected. The 2 utensils selected were identical in size and shape, but the bottom of one had the usual bright finish, while that of the other was blackened with a lacquer-like material. The 2 pans are shown in figure 2 with handles removed as they were used in the tests. Another view of the same utensils showing the character of their bottoms is shown in figure 3.

Several factors other than their popularity were also instrumental in the selection of the aluminum utensils. In the first place, aluminum is a material of low specific heat and high heat conductivity, which means, as will develop later, a minimum of error in the computation of the energy transfer of the test units. In the second place, since the sides of the utensils are highly polished, radiation losses from the utensil will be a minimum, which also aids in reducing the error in the computation of the heat energy transferred by the units. Lastly, the aluminum utensils used were designed especially for electric range surface use.

One of the most important items in the determination of the heat transferred by the units is the method of measuring the temperature of the water contained in the aluminum vessels. Previous investigators have employed ordinary mercury-in-glass thermometers or thermocouples. Both of the latter methods give temperature indications at one or more points in the liquid dependent upon the number of such instruments used. The temperature of the water in the vessel cannot be the same throughout its volume, because of the convection currents which are readily discernible in it. Therefore, a device capable of indicating an average of the temperatures existing throughout the volume of the water gives much more representative temperature values. It was therefore decided to construct a resistance thermometer with the resistance element spread out over a considerable cross section of the water volume. The resistance thermometer constructed is shown in figure 4. The light framework is of bakelite, and the resistance element is a number 40 American wire gauge nickel-alloy wire expressly made for the purpose. The fineness of the wire and its high resistance per unit length (16 ohms per foot) make it very sensitive to changes in temperature. Another desirable feature of the resistance thermometer is its extremely short time lag in comparison with the long time lag of a mercury-in-glass thermometer.

Figure 3. Bottoms of pans, showing bright and black surfaces

The resistance thermometer was calibrated with a mercury-in-glass thermometer by immersing both in a constantly stirred transil-oil bath, the temperature of which

was changed very slowly. Several points on the calibration curve obtained were checked by immersing the resistance thermometer in liquids, the boiling points of which were accurately known. It was found that the resistance of the thermometer was not a linear function of temperature, but followed a law of the form

$$\log r = a + bT$$

where r is the resistance in ohms at the temperature T degrees centigrade, and a and b are constants. In this case, a had the value 2.162, and b the value 9.92×10^{-4}.

By means of the resistance thermometer, it is possible to determine the temperature of the water at any time t seconds from the start of the test, and, from the temperature measurements, the heat transferred from the unit to the utensil and water may be calculated by employing the following equation:

$$W_o = (w + c_{Al}w_{Al})(T_t - T_o) \qquad (2)$$

in which W_o is the heat energy in calories transferred by the unit, w is the weight of the water used in grams, c_{Al} is the mean specific heat of aluminum in calories per gram per degree centigrade ($c_{Al} = 0.217$), w_{Al} is the weight in grams of the aluminum pan used, T_t is the temperature of the water in degrees centigrade at time t seconds from the start of the test, and T_o is the temperature of the water at the start of the test in degrees centigrade.

The specific heat of water departs so slightly from unity over the range from 20 to 100 degrees centigrade, the temperatures encountered in the tests, that it is impractical, in view of other limits of measurement, to consider it other than unity. The same statement may be applied to the specific heat of aluminum. It will further be noted from equation 2 that it is assumed that the aluminum pan experiences the same temperature change as the water. This, of course, is not strictly true, especially as regards the bottom of the pan. However, since the specific heat and weight of the aluminum pan are small compared to the corresponding values of the water used, and since the heat conductivity of aluminum is so very high, the error resulting from this assumption is negligibly small.

It will be noted further that equation 2 does not account for any heat transfer between unit and utensil represented by possible evaporation of water. This is permissible because special precautions were taken to greatly minimize evaporation. Normally, of course, the evaporation of water below the boiling point represents a heat transfer which is not negligible. The amount of heat transfer represented by evaporation at any particular temperature, however, is very difficult to determine because of the variation in the rate of evaporation and the heat of evaporation with temperature. It is, therefore, imperative that evaporation be reduced to a negligible quantity.

It was found possible to do this by forming a thin film of a low-vapor-pressure oil over the surface of the water just prior to starting the tests, and by halting the tests at temperatures slightly below the point at which violent ebullition of the water began to take place. The success of this method is attested by the fact that the upper portions of the temperature-time curves remained straight after its adoption, where previously they had tended to curve to the right due to the evaporation loss. The loss of water by evaporation was reduced from approximately 7 per cent to 0.5 per cent, which made the evaporation heat loss negligible up to the boiling point.

Calculation of Efficiencies of Heat Transfer

The efficiency of any piece of apparatus is defined as the amount of energy delivered by the apparatus expressed as a percentage of the energy delivered to it. Since the necessary values of energy input to, and heat transfer from, the surface units tested have been determined, it is now possible to calculate an efficiency of heat transfer for the units. This value may quite obviously be obtained by dividing equation 1 into equation 2, and may be expressed as follows:

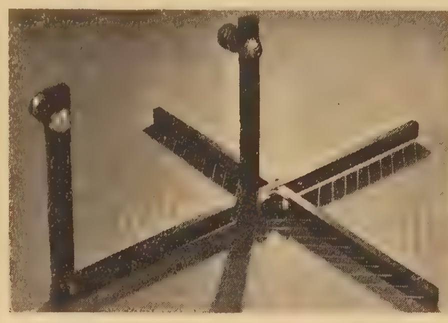


Figure 4. Frame and wire for resistance thermometer

$$\eta = 100\left(\frac{W_o}{W_t}\right) \qquad (3)$$

in which η is the efficiency of heat transfer of the unit in per cent, W_o is the heat energy transferred by the unit in calories up to, and including, the time t seconds which have elapsed since the start of the test, and W_t is the energy input to the unit in calories during the same time interval.

While the efficiency defined in equation 3 is important, because it is a direct measure of the amount of useful energy transferred by a given unit, it is taken over time intervals measured successively from the origin, and hence gives no clue as to the efficiency with which the unit is transferring heat energy to the utensil and water at any particular instant. The instantaneous efficiency of heat transfer may, however, be obtained by plotting energy output W_o values against energy input W_t values, and determining the slope at various points along the resulting curve. The values of elapsed time corresponding to the several slope values may be easily obtained by reference to a curve of elapsed time values plotted against corresponding energy input W_t values. Mathematically, of course, the instantaneous efficiency may be indicated simply as follows:

$$\eta_t = 100\frac{dW_o}{dW_t} \qquad (4)$$

in which η_t is the instantaneous efficiency of heat transfer in per cent.

Fundamentally, the instantaneous efficiency, η_i, is the quotient of 2 time rates, that is,

$$\eta_i = 100 \frac{\frac{dW_o}{dt}}{\frac{dW_i}{dt}} \qquad (5)$$

and when expressed as such is, perhaps, more capable of complete understanding. When expressed as indicated in equation 5, the instantaneous efficiency simply expresses the fact that the instantaneous rate at which useful energy is being transferred by a given surface unit is a certain percentage of the rate at which energy is being supplied to the unit.

The meaning of the 2 efficiencies defined by equations 3 and 4 may, perhaps, be made clearer by comparing them with the 2 efficiencies of, say, a power transformer. The efficiency defined by equation 3 is comparable with the over-all or all-day efficiency of the transformer, while that defined by equation 4 is comparable with the efficiency of the transformer at any particular load or instant during the day. Because of the similarity of the efficiency defined by equation 3 to the over-all or all-day efficiency of the transformer, it has been termed the over-all efficiency of the surface units, and will be referred to as such to distinguish it from the instantaneous efficiency.

Experimental Procedure

The surface unit to be tested was in each case placed in the range for which it had been designed, connected as it would be in actual use, and the range then connected to a 3-wire a-c system, the voltage of which could be readily controlled. The instrument leads from the voltmeter and the potential circuit of the watt-hour meter were connected directly across the terminals of the test unit, so that the watt-hour meter readings would not include the losses occurring in the range wiring or the current circuit of the watt-hour meter.

In each case, rated voltage, that is, the value of rated voltage required to give rated wattage, was maintained constant at the terminals of the test unit. In order that the voltage at the terminals of the unit should be very close to its rated value at the instant the test unit circuit was closed, the voltage of the supply source was adjusted to a value slightly higher than the rated value previous to starting the test. The requisite supply voltage value was determined by previous experiment.

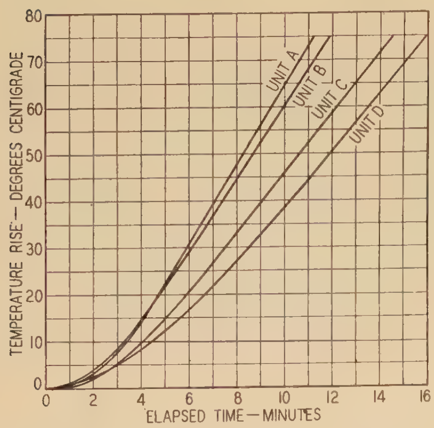


Figure 5. Temperature rise of water in bright-bottomed aluminum pan placed upon several types of 1,200-watt electric-range surface units

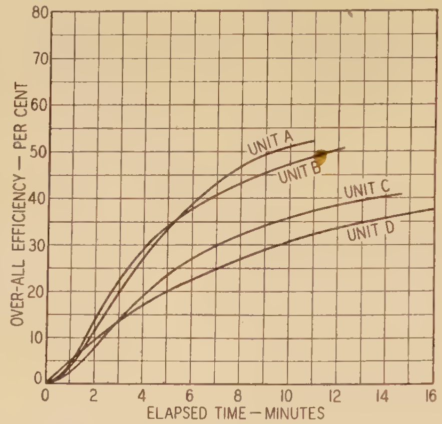


Figure 6. Over-all efficiency of several types of 1,200-watt electric-range surface units when used with a bright-bottomed aluminum pan

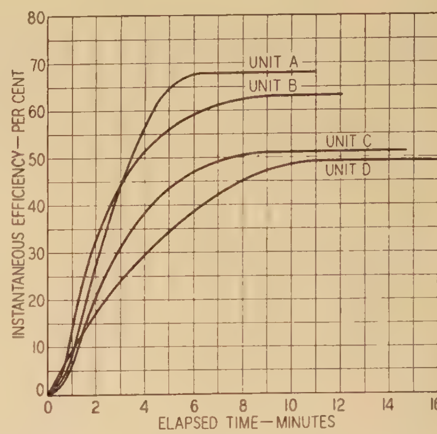


Figure 7. Instantaneous efficiency of several types of 1,200-watt electric-range surface units when used with bright-bottomed aluminum pan

Units at room temperature at start of test. Weight of water used, 1,250 grams (2.76 pounds); weight of pan, 418.8 grams (0.92 pound)

The following procedure was employed in determining the efficiency values for the 4 1,200-watt surface units tested. The identical procedure was used for all units with both bright- and black-bottomed aluminum pans.

The resistance thermometer was placed in the particular pan to be employed, and the utensil then placed upon one pan of a beam balance, and the combined weight noted. The usual amount of water, 1,250 grams, was then admitted to the utensil, care being taken to see that no drops of water were splashed on the exterior of the pan or the balance. Then, with the pan still upon the balance, a thin oil film was formed over the water surface by dropping a slight amount of apiezon oil on it from a dropper. The weight of the oil thus added was found to be insignificant. The utensil was then removed from the balance, and carefully centered over the particular unit to be tested. Connection of the resistance thermometer to a precision bridge was then made, after which the thermometer was carefully centered in the pan, and the bridge balanced. No lid was employed in any of the tests.

Then, with the bridge balanced, the supply circuit was closed on the test unit, not by means of the unit switch on the range, which was in all cases left on "high" during the tests, but by means of a knife switch in the supply lines. A stop watch was started at the instant the switch was

closed. Thereafter, at a signal from the observer operating the bridge, indicating that the bridge was in balance, simultaneous readings of elapsed time, revolutions of the watt-hour meter, and resistance of the resistance thermometer were noted and recorded.

Each test run was halted at a point slightly below the boiling point corresponding to barometric conditions prevailing at the time of the test. When the selected final temperature was reached, the test unit circuit was opened, the stop watch stopped, and the utensil removed from the unit. As soon as possible after removing the utensil from the unit, a well-fitting lid was placed on the utensil, and the utensil and contents weighed to determine what loss in weight, if any, had taken place. If an unusually large difference existed between the original and final weight values, the test was in all cases repeated until the difference was brought to within 0.5 per cent.

Results

The results obtained from the data secured in the tests are presented in curve form in figures 5, 6, 7, 8, 9, and 10. Figures 5, 6, and 7, as indicated, are from data obtained on the test units using the bright-bottomed aluminum pan, while figures 8, 9, and 10 give corresponding values for the same units using the black-bottomed aluminum pan.

Discussion of Results

An examination of figures 5 and 8 shows that the temperature rise of the water becomes a linear function of the elapsed time after a certain time interval. It follows, therefore, that the heat energy transferred by each unit also becomes a linear function of the elapsed time, and hence a linear function of the energy input to the heating unit, since the energy input is directly proportional to the elapsed time. Over the linear range, the heat energy, W_o, transferred by the unit may be expressed as follows:

$$W_o = cW_i - d \tag{6}$$

in which c and d are constants. If now both sides of equation 6 are divided by W_i, the following result is obtained:

$$W_o/W_i = c - d/W_i \tag{7}$$

The left-hand side of equation 7 will be immediately recognized as the over-all efficiency of the unit, η. Hence, equation 7 may be written,

$$\eta = c - d/W_i \tag{8}$$

Now, as time, and consequently W_i, increases, it is seen that the over-all efficiency approaches, as a limiting value, the constant c in equation 8. Examination of figures 6 and 9 demonstrates that the over-all efficiency does tend to approach certain limiting values in both cases.

Now differentiate equation 6, obtaining the result,

$$dW_o/dW_i = c \tag{9}$$

The left-hand side of equation 9 is, of course, the instantaneous efficiency of the unit, η_i. Hence, over the linear portion of the curve,

$$\eta_i = c \tag{10}$$

and the instantaneous efficiency curves should become straight lines parallel to the time axis. Examination of figures 7 and 10 shows that such is the case.

The following deduction may now be drawn from a consideration of the preceding discussion and a critical examination of equations 8 and 10. When any of the surface units tested is used as previously indicated in this paper, the over-all efficiency of the unit approaches a limiting value which is identical with the maximum value attained by the instantaneous efficiency of the unit. The importance of the above statement may be made clearer by considering the fact that, under the condition stated, units

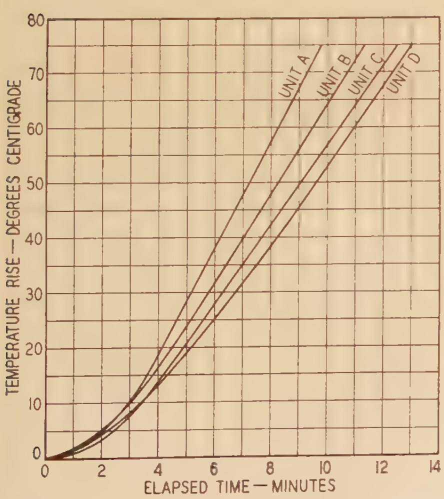


Figure 8. Temperature rise of water in black-bottomed aluminum pan placed upon several types of 1,200-watt electric-range surface units

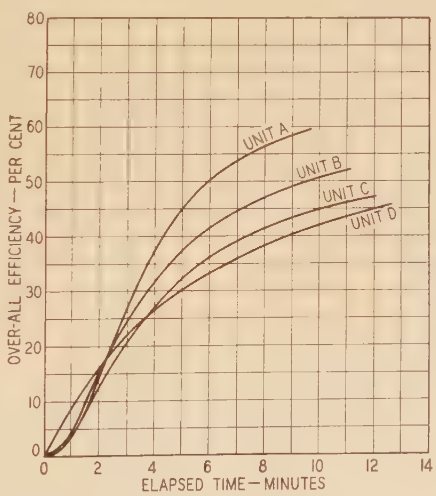


Figure 9. Over-all efficiency of several types of 1,200-watt electric-range surface units when used with a black-bottomed aluminum pan

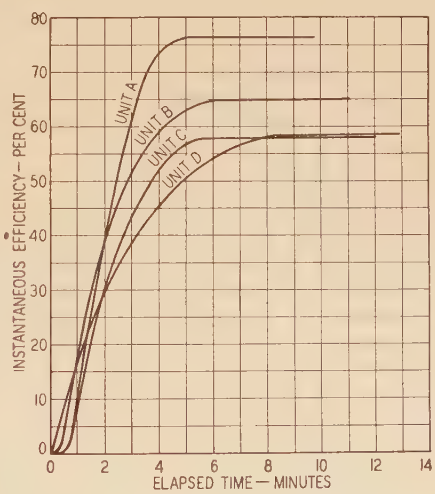


Figure 10. Instantaneous efficiency of several types of 1,200-watt electric-range surface units when used with black-bottomed aluminum pan

Units at room temperature at start of test. Weight of water used, 1,250 grams (2.76 pounds); weight of pan, 430.5 grams (0.95 pound)

such as A and B can never transfer more than approximately 65 per cent of the energy they consume, and units such as C and D can transfer only about 50 per cent of their energy input when, as is usually the case, bright-bottomed pans are used.

It may be seen from figure 10 that if a black-bottomed pan is used, approximately 76 per cent of the energy consumed by unit A may possibly be realized. It may further be noted that but a small increase in the percentage of energy realizable is obtained by using the black-bottomed pan with such a unit as B. For units such as C and D, it is seen, the percentage of consumed energy which may possibly be realized if the black-bottomed pan is used is approximately 58 per cent, which may be compared with the value of 50 per cent possible with the same units using the bright-bottomed pan. The magnitude of the increase in efficiency to be obtained by the use of a black-bottomed utensil is shown in table I.

As is to be expected, the open-coil type unit D has the largest percentage increase in instantaneous efficiency. This is because this unit transfers heat chiefly by radiation, and the efficacy of the black-bottomed pan lies in the fact that a black surface is a more efficient absorber of radiant energy than other types of surfaces.

Suggestions for Possible Improvement

Unit A. The already relatively high efficiency of this unit is due to the small amount of mass in the regions of high temperature, the use of a surface beneath the unit for reflecting the radiant energy directed downward by the unit, and the opportunity provided for air convection currents to pass easily from the lower surfaces of the heating elements to the bottom surface of the utensil. However, since this unit is constructed by spiraling lengths of circular tubing containing the heat-developing resistance, there is at best a series of line contacts between the heating element and the utensil. Irregularities in the units introduced by warping reduces the line contacts between unit and utensil to a series of point contacts, which permits but a very small amount of heat transfer by conduction to take place from the unit. The efficiency of this unit would undoubtedly be much improved if the upper surfaces of the heating element tubes were flattened, and if the tubes were so mounted that the flat surfaces would remain in the same plane. Some improvement in efficiency would also be expected if the reflector plate placed beneath the heating element was treated with a reflecting surface which would not be destroyed by the heat of the unit.

Unit B. This unit ranks second in efficiency, and is quite well designed for transferring heat to a utensil by thermal conduction. The surfaces of the heating elements are flat, and are rigidly supported to prevent warping. The mass of this unit could probably be reduced to some extent by a reduction in the size of the cast iron supporting structure, and the heat transfer efficiency of the unit improved by operating it at a higher temperature in order to obtain more heat transfer by radiation. The relatively small amount of heat transferred through the medium of radiation by this unit is shown by the fact that its instantaneous efficiency was increased but 2.8 per cent by using the black-bottomed utensil.

Table I. Influence of Utensil Bottom Finish on Efficiency

Unit	Maximum Instantaneous Efficiency (Per Cent) Bright Bottom	Maximum Instantaneous Efficiency (Per Cent) Black Bottom	Increase (Per Cent)
A	68.1	76.4	12.2
B	63.3	65.1	2.8
C	51.3	57.8	12.7
D	49.2	58.5	18.9

Unit C: The efficiency of this unit would undoubtedly be greatly improved if the surface it provides for the utensil to rest upon was flattened to increase the amount of heat transferred by conduction. As the unit is constructed at present, heat transfer from it to the utensil takes place largely through radiation as is shown by the 12.7 per cent increase in instantaneous efficiency secured by the use of the black-bottomed utensil. A reduction of the mass of material subjected to high temperatures would, no doubt, also improve the efficiency of the unit.

Unit D. The transfer of heat from this open-coil type of unit takes place almost exclusively through the medium of radiation. The character of the utensil bottom, therefore, has a marked influence on the efficiency of heat transfer of the unit. This is clearly shown by the 18.9 per cent increase in instantaneous efficiency secured through the use of the black-bottomed utensil. Not a great deal can be done to increase the efficiency of this type of unit through changes in construction, except, perhaps, changes in the form of the ceramic used to support the heating coils made possible by future research in the ceramics field.

Conclusions

1. There is very definite need for marked improvement in the heat-transfer efficiency of electric range surface units.

2. When used under the conditions outlined in this paper, the efficiency of heat transfer of each unit approaches a limiting value which it cannot exceed.

3. A very definite increase in the limiting value of the heat-transfer efficiency of a given unit, used with a bright-bottomed pan, may be obtained by using a black-bottomed pan.

4. The percentage increase in efficiency obtained by employing a black-bottomed utensil is greatest for those units depending principally upon radiation as the medium of heat transfer.

5. The enclosed type of surface unit, in general, is superior to the open-coil type of unit.

References

1. APPLICATION OF ELECTRICITY IN THE KITCHEN, E. Marec. *Revue Generale de l'Electricite*, volume 26, number 10, September 7, 1929, pages 375–80.

2. TESTING OF ELECTRIC COOKING EQUIPMENT, P. Seehaus. Association Suisse des Electriciens *Bulletin*, volume 22, numbers 10 and 11, May 15, 1931, pages 225–39, and May 29, 1931, pages 260–70.

3. ELECTRIC COOKING AIDED BY BLACK BOTTOM UTENSILS, A. S. Loizeau. *Electrical World*, volume 99, 1932, page 997.

4. COMPARISON OF RANGE ELEMENTS, G. J. Mickler. *Electrical World*, volume 91, 1928, page 199.

5. THERMAL EFFICIENCY OF SURFACE UNITS IN ELECTRIC RANGES, V. W. Swartz. *Journal of Home Economics*, volume 23, 1931, pages 459–64.

Present-Day and Probable Future Electrical Applications in Aircraft

By W. V. BOUGHTON

THE ELECTRICAL system plays a very important part in present-day airplanes. In addition to lighting the plane and starting the engines, it is required to furnish power for radio, instruments, landing gear, flaps, and remote operations. The fact that electrical operation leads to more convenient and often lighter installations makes it desirable to use it whenever applicable.

A description of the electrical installation in the Douglas sleeper transports appears to present the best way of explaining present-day electrical applications in aircraft.

The airplane is wired in 2 main feeder circuits with the intermittent and continuous loads so divided that the total drain on each circuit is approximately equal for a given period. This is approximately as follows:

Circuit Number 1

Interior lights	408 watts
Navigation and passing light	48 watts
Deicers	48 watts
Argon lights	36 watts
Maximum continuous load	540 watts
One landing light	444 watts
Cigarette lighter	60 watts
Seat belt signs	25 watts
Maximum intermittant load	529 watts

Circuit Number 2

Cockpit and instrument lights	32 watts
Electrical instruments	16 watts
Airspeed head heater	75 watts
Landing gear signal lights	13 watts
Radio receivers	120 watts
Maximum continuous load	256 watts
Landing gear warning horn	60 watts
Fuel and oil-pressure warning lights	13 watts
One landing light	444 watts
Radio transmitter	890 watts
Maximum intermittent load	1,407 watts

The initial load on starting is about 2,520 watts for each engine dropping almost immediately to about 1,935 watts. This is usually carried by the battery cart at the airport. Each circuit is supplied from a 12-volt 85-ampere-hour storage battery and a 50-ampere 14.5-volt constant-potential generator, driven by the airplane engines. In case of mechanical or electrical failure of one source of supply, either or both circuits can be switched to either battery and generator. A remote-controlled master switch enables the pilot to open the battery circuits instantly in an emergency and also to connect the airplane circuits to a receptacle in the side of the fuselage for plugging in a battery cart while at the air terminal. This permits the use of the electrical equipment in the plane before taking off, without running down the batteries. The entire system is single wire with the metal airplane structure as the return.

The batteries are located in the fuselage in tight compartments, the bottoms of which are platforms mounted on telescoping tubes. When these platforms are lowered the batteries can be placed on them from the outside of the airplane, and, when raised into place the batteries are automatically connected into the circuits by means of plug- and jack-type connectors. As it is possible to change them by this method in less than 3 minutes, no delay in the departure of the plane would be occasioned because of the necessity of installing a fully charged battery.

The main electrical distribution box is located adjacent to the batteries and contains the master switch, circuit-selector switches, generator-control boxes, starter relays, landing-light relays, meter shunts and resistors, and individual circuit fuses. These are readily accessible in the air or on the ground.

Located above the windshield in the pilot's cockpit are the various switches for lights, ignition, starting, airspeed head heater, seat belt warning signs, and the meters in the generator circuits. Below the windshield is the instrument panel with the navigation and engine instruments. On this panel are located the landing gear warning lights, the door-open warning light, the airspeed head heater warning light, the fuel- and oil-pressure warning lights, the co-pilot-to-stewardess call light and button, and a number of electrically operated instruments.

In large airplanes, the use of mechanical tachometers, capillary tube thermometers, and mechanical fuel-quantity gages is impractical. These instruments are electrically operated in the Douglas sleeper transports. The tachometers consist of small magneto generators mounted on and driven by the airplane engines. The voltage output varies directly with the speed and the indicators in the cockpit are calibrated to read directly in revolutions per minute. The electric thermometers which are used to measure the temperature of the incoming carburetor air and the incoming oil are of the resistance bridge type. The fuel-quantity gauges consist of potentiometers with the moving arms actuated by the tank floats and voltmeters calibrated in gallons to measure the voltage drop through the resistances.

The cockpit is lighted by small automotive-type instrument lamps and 2 small spot lights with universal mountings. In addition 2 argon lamps are located so as

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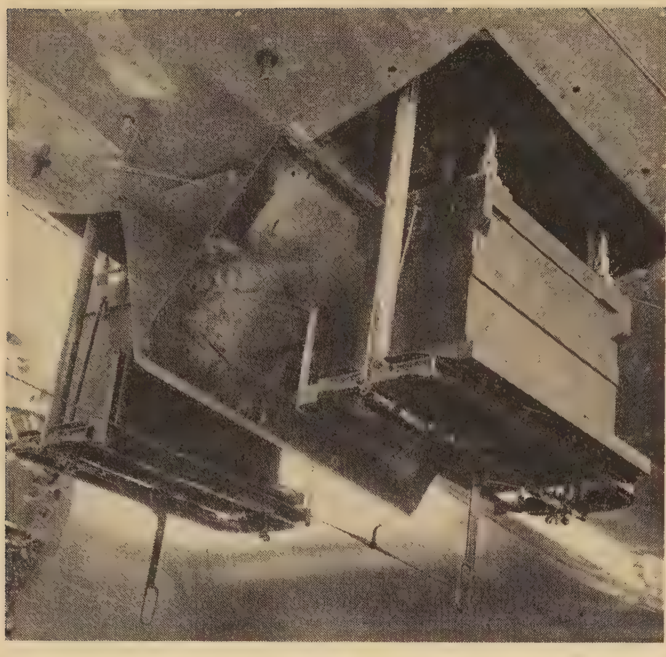

Figure 1

to provide ultraviolet fluorescent illumination of the instrument dials for night flying when general illumination in the cockpit would be undesirable. These argon lights are supplied by a small rotary converter delivering 110 volts. The degree of illumination from all cockpit lamps is controlled by rheostats.

The front passage to the cabin, the cabin itself, the dressing rooms, lavatories, and rear compartments are lighted by ceiling lights. In addition, there is a reading light by each seat, a reading light for each upper berth and provision for plugging in a table light in each section. Located near the aisle floor are small night lights for use after the passengers retire.

Each seat and each berth has a push button to call the stewardess. Each station has a small light and colored jewel, visible from either end of the aisle to indicate the origin of the call. When the button is pushed, a buzzer sounds at the stewardess' station and the light at the calling station comes on and locks on electrically through a relay. The light is reset with a switch at the stewardess' station. An electric sign for use during landing and taking off is located at each section. It is controlled by the pilot and bears the wording "No Smoking. Please Fasten Seat Belts."

The airplane is equipped with a radio receiver and transmitter for 2-way communication with the ground, a radio beacon receiver for use with the beam transmitted by the Department of Commerce stations located along the airways and an auxiliary stand-by receiver. The transmitter is rated at 50 watts output and both it and the 2-way receiver are designed for continuous wave, interrupted continuous wave, and phone. The filaments of all the radios are supplied directly from the 12-volt system and the plate circuit is supplied from dynamotors operating from the 12-volt supply. Small batteries are carried for the emergency operation of the stand-by receiver. Two jacks, located in the side of the fuselage at the battery cart receptacle, provide means for plugging in a telephone set to communicate from the field to the pilot's cockpit before taking off. An interphone system between the cockpit and the cabin permits the stewardess to communicate with the pilot and co-pilot. Radio wiring and equipment weights are about as follows:

Transmitter and receiver for 2-way communication	71 pounds
Beacon receiver	23 pounds
Auxiliary stand-by receiver	18 pounds
Transmitting dynamotor } Receiving dynamotor }	47 pounds
Emergency batteries	12 pounds
Conduit	15 pounds
Junction boxes, brackets, and supports	36 pounds
Wiring	14 pounds
Total	236 pounds

For night flying, navigation lights are located on the wing tips and the rear of the fuselage. A landing light is located in the leading edge of each wing outboard of each engine nacelle and a red passing light is incorporated in the left-hand landing light. These landing lights are equipped with 12-volt 35-ampere bulbs which, because of their rather high design factor of 25 lumens per watt, have a life of only 100 hours.

In each engine nacelle, or on each engine, are mounted the carburetor air-temperature resistance bulb, oil temperature-resistance bulb, engine-temperature thermocouple, tachometer generator, 12-volt generator, starter, magnetos and booster coil, and exhaust-gas analyzer cell. The engine section wiring is connected into plugs at the firewall to permit rapid disconnection for engine change This helps to reduce maintenance delays in schedules.

Other electrical applications encountered in aircraft are electromechanical or electrohydraulic operation of landing gear and flaps. Deicing of wings and tail surfaces is accomplished by inflating and deflating rubber strips along the leading edge. The valve which controls this is electrically driven as is the pump which delivers alcohol to the propellers and carburetors for ice removal.

The wire used in these airplanes is in accordance with the United States Army Air Corps specifications. It consists of a multistrand flexible conductor, insulated with 2 layers of varnished cambric and a lacquered, woven cotton braid. This type of wire weighs less than rubber insulated wire and has a smaller outside diameter, permitting the use of smaller conduits

Because of the necessity for reliable radio operation, it is essential that all radio interference arising from the operation of the airplane be kept to the absolute minimum. The proximity of the antenna to the possible sources of interference makes it necessary to completely enclose every portion of the electrical system in a tight electrostatic shield, thoroughly bonded at frequent intervals to the airplane structure. This is accomplished by using a metal conduit and junction-box system and enclosing all equipment which is not inherently shielded by its construction, in shielding boxes. Aluminum and aluminum alloys are used for this purpose. The radio wiring is isolated from the main wiring by installing it in a separate conduit sys-

tem. The question of adequately shielding electrical equipment is one which the entire electrical industry may have to face in the near future, especially when television comes into general use.

Bonding consists of connecting electrically all metal parts of an airplane. Its purpose is: To increase the capacitance between the airplane and the radio antenna; to prevent absorption of the radiated energy of the radio transmitter by electrically isolated metal parts; to eliminate the danger of sparks occurring between metal members between which there exists a difference in potential caused by the collection of static charges; to eliminate noises produced in the radio receiver which are caused by the varying resistances between rubbing or vibrating metal parts; to lower the resistance of the metal shielding. The all-metal structure of the transports is inherently bonded and such parts as conduit, fuel and oil lines, etc., are bonded by their attaching parts. These attaching parts (clamps, brackets, etc.) are usually located at intervals of 18 to 20 inches. In places where this interval is greater, bonding strips of tinned copper braid are used to connect to the structure. This bonding interval of about 18 inches is necessary to prevent the secondary radiation of energy when standing waves are generated on long, ungrounded parts, and to provide sufficient low resistance paths to the structure to insure the effectiveness of the shielding. Fuel and oil tanks are bonded at diagonally opposite corners. All bonding connections should have a resistance of not more than 0.002 ohm.

The problem of weight is one with which the airplane designer is constantly confronted and the electrical installation in a plane the size of the Douglas sleeper transport requires serious consideration in this respect. It is estimated the completed installation will weigh about 772 pounds divided as follows:

Wire	135
Conduit	85
Junction and shielding boxes	136
Equipment	416

The equipment weights are divided as follows:

2	85-ampere-hour 12-volt batteries	155 pounds
2	Generators and regulators	62 pounds
2	Battery compartments	34 pounds
2	Starters	66 pounds
	Lights	57 pounds
	Switches, relays, etc	42 pounds
	Total	416 pounds

When designing electrical equipment for aircraft, this question of weight must be kept in mind as it is possible to effect considerable saving by the use of proper materials. As an example of what can be done, we have recently had designed and built a 3-position single-pole double-throw 200-ampere switch which weighed 2.2

Figure 2. Electrical panel above windshield. Radio controls above and below ignition switch

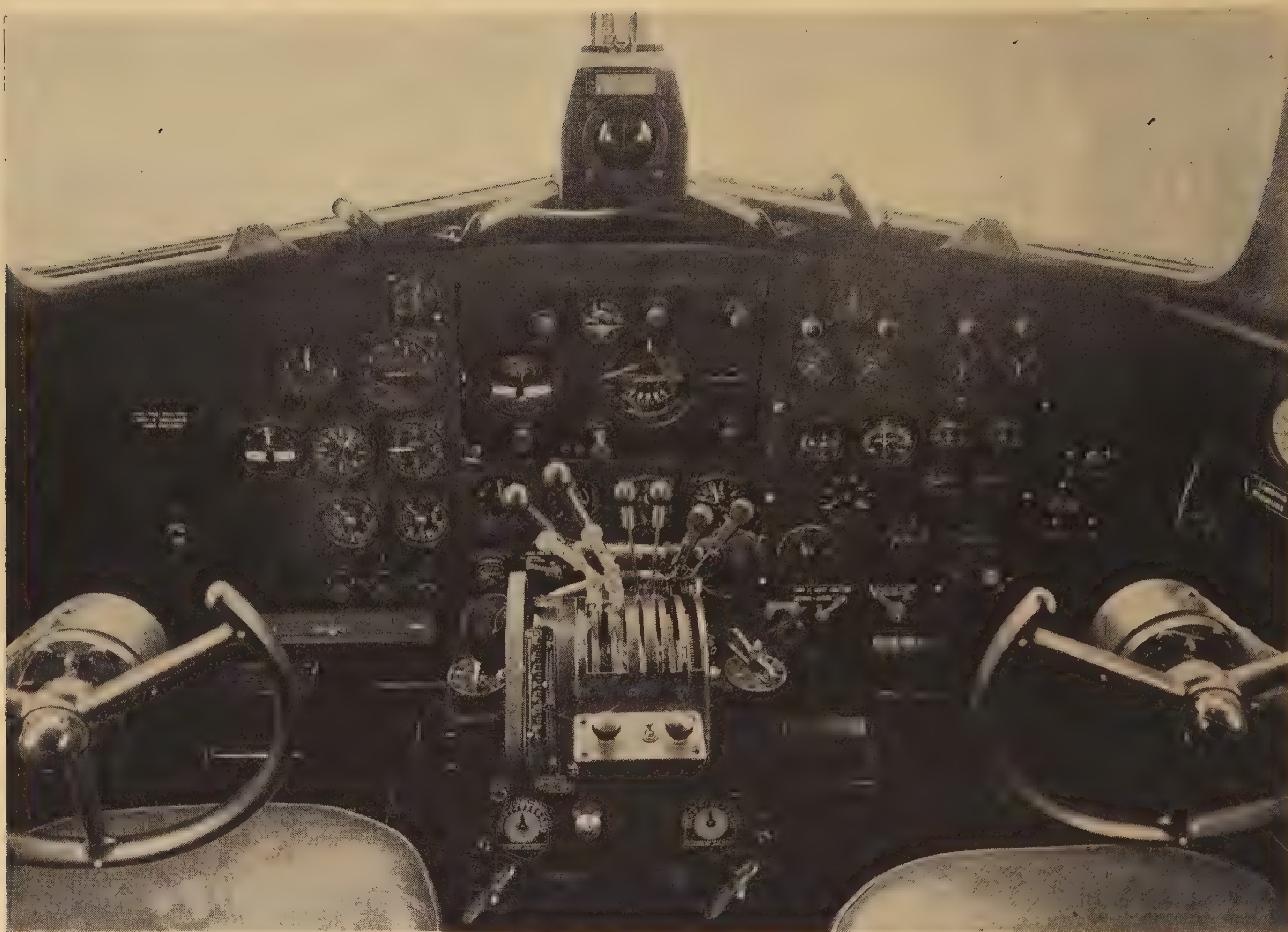

Figure 3

pounds. However, weight should never be saved at the expense of reliability.

Another factor which enters the design problem is the matter of operating temperatures. Equipment for use on aircraft must be capable of operating through a range of from −30 degrees Fahrenheit to +130 degrees Fahrenheit without change in lubricant or any other adjustment that is not wholly automatic. These extremes may be encountered within a period of 30 minutes.

Operating noise must be kept to the absolute minimum. Considerable weight, expense and time are spent in soundproofing the interiors and any equipment which introduces more noise is undesirable. The sound level in the present transports is such that the operation of the small toggle switches for the lights can be distinctly heard.

It becomes evident on studying today's large airplanes and tomorrow's larger ones, that an increase in the supply voltage would help considerably to keep the weight down. This would seem to be rather easily accomplished by placing the 2 12-volt batteries in series and using 24-volt generators. However, weight is not the only problem.

The amount of electrical equipment used is such that the present power supply is hardly adequate and with the increasing amount of equipment on larger planes, it is imperative that a larger source be made available. The larger airplanes require from 10,000 to 20,000 watts available continuously and this supply should be independent of the airplane engines. There are units being designed and built to meet these requirements. They consist of small 4-cycle gas engines driving generators and possibly some of the other accessories now driven by the airplane engines such as vacuum pumps, oil pumps, etc. To guard against failure, 2 such complete units will be carried.

A great deal of thought has been given to supply characteristics and it has been agreed that alternating current at 115 volts is the logical choice. This voltage makes available many commercial developments and the inherent flexibility of alternating current makes it very desirable.

A study of 60-cycle equipment shows that a large system such as has been outlined would involve considerable weight. Quite a saving could be made by using some frequency higher than 60 and a study has been made of frequencies as high as 800 cycles.

It is believed that the amount of power involved and the length of the transmission lines are such that no serious reactance trouble will be encountered. However, there is considerable doubt that satisfactory motor characteristics are possible at 800 cycles.

Development work on equipment for this frequency has been under way for some time and this problem may be solved shortly.

Figure 4. Transmitter and receiver for 2-way communication

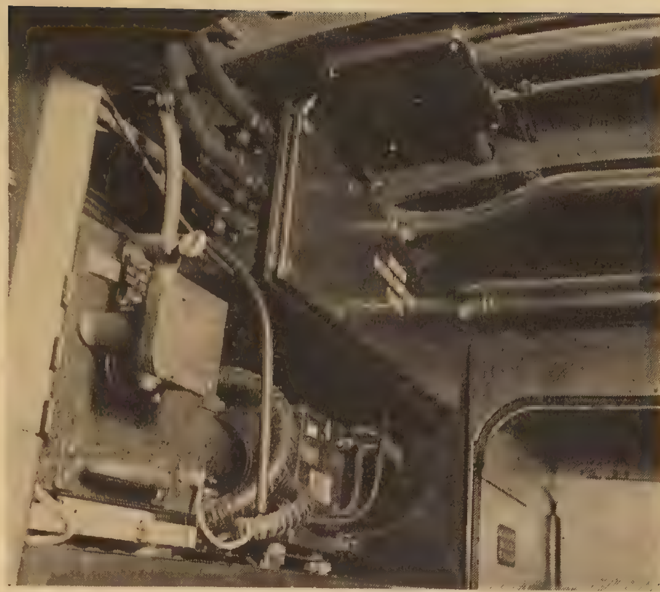

Figure 5. Radio beacon receiver, dynamotor, and stand-by receiver

It is known that satisfactory 360-cycle motors can be obtained and that radio filament supply at this frequency is feasible. A large percentage of the possible weight saving at 800 cycles is possible at 360 cycles. This or some other frequency lower than 800, may prove to be the best compromise. There is also the possibility that the various loads may become great enough to warrant the use of a double-frequency generator, supplying high frequency for radio plate supply, lighting and heating, and some lower frequency for motors and radio filaments.

Both single- and 3-phase supply have been considered and the advantages and disadvantages of each are about balanced. Of course, polyphase motors have an advantage over single-phase where power is required.

With airplanes steadily increasing in size and with a sufficiently large electrical supply, there is almost no limit to the possible applications in the future. All engine instruments will be electrical, possibly of the selsyn type. Various remote indicators for flaps, landing gear, fuel and oil quantity are already being used. Heater units to prevent carburetors and windshields from icing up and to provide hot water in the lavatories may be installed.

Lighting problems will be greatly simplified with a larger supply available. It will be possible to furnish adequate light for reading and general illumination comparable to that found in a modern home. Landing lights of much greater intensity have been developed. Development work on lamps has progressed to the point where satisfactory 115-volt lamps for aircraft are available in 6-, 15-, 20-, 25-, and 50-watt sizes. These are obtainable with the standard automotive bayonet base up to and including the 25-watt size. The 25- and 50-watt sizes are obtainable with the medium bayonet base. Landing-light lamps have been made in the 500-, 750-, 1,000- and 1,500-watt sizes with reasonably concentrated filaments. Tests indicate that all of these lamps are sufficiently rugged to have a reasonable life.

One of the problems of air transportation is that of serving satisfactory meals aloft. These large planes of tomorrow will have an electrically equipped galley where appetizing meals can be prepared. Light-weight hot plates, thermally insulated to prevent heat loss by radiation, electric mixers, and special cooking utensils will be needed. Making coffee at from 16,000 to 20,000 feet may require some experimenting, when the lower atmospheric pressure is considered. Electric refrigeration will be included.

Electric razors, now used by many airlines, curling irons and other modern conveniences will be available on overnight planes. Passenger comfort will be stressed and any electrical appliances contributing thereto will receive consideration.

Radio equipment of greater power for 2-way communication, radio direction finding and blind-landing equipment will be standard on all planes. With alternating current available, the high-voltage plate supply will be furnished by step-up transformers, rectifiers, and filters instead of by dynamotors. When transmitters with ratings of 1,000 to 2,000 watts output are considered, the size and weight of the power supply becomes very serious. It is here that great savings in copper and iron weight can be made by using a supply frequency well above 60 cycles. Transmitters of this power are not unreasonable when transoceanic flying, with the attendant need for absolutely reliable communication, is considered. Broadcast reception and television may be furnished for the passengers' amusement.

In planes designed for high-altitude flying, various indicators and controls, electrically operated will doubtless be used. Air conditioning will be necessary

The aviation industry is dependent upon the electrical engineers for these and other developments and it is hoped that this article has been able to present a general picture of the probable future needs.

Proposals for the Administration of Federal Power in the Pacific Northwest

By H. V. CARPENTER
FELLOW AIEE

Synopsis

This paper undertakes to state briefly the plans of organization of the Ontario Hydro-Electric Commission, the British Grid, the Tennessee Valley Authority, and then the proposals made by the planning bodies and in bills submitted to Congress for the public administration of power from Bonneville and Grand Coulee.

(I have not received Senate Bill No. 2092, and H.R. 6151, a bill prepared by the Senators of Oregon and Washington, which is more similar, I suspect, to their bill described herein which died with the 74th Congress. I would have been glad to add a summary of this bill if time had permitted.)

SINCE the depression has led the Federal Government into a number of great public-service construction projects, the method of administering the power to be produced has become of increased interest. Sale of power from Muscle Shoals has been a troublesome problem in the Congress at frequent intervals ever since the service became available. Now merged with the Tennessee Valley Authority the sale of the same power continues to find its way into the courts or to be the subject of legislation. This is not strange since the federal administration of such a utility is a new thing in the United States, and its promise of permanency gives the subject major importance.

Oldest of the government works for handling power on a large scale in North America is the Hydro-Electric Power Commission of Ontario. Under the wise and able administration of Sir Adam Beck, this organization has made a most valuable contribution to our fund of experience in governmental administration of a vast public utility. The Commission consists of 3 persons appointed by the Lieutenant Governor in Council, one of whom must be a member of the Executive Council of the Province. One member is named chairman and is the only one that is drawing a salary. The Commission chooses its staff, the staff members choose their own assistants, and the administration within the organization has been much the same as that of a private corporation, including a system of retirement funds and insurance for employees and the usual wide latitude granted to department heads in carrying out individual administrative duties. The Enabling Act refers to the Commission as a body corporate without capital. Its precise legal status has been determined gradually through later acts which have amended the original status, and through the results of legal procedure.

A unique feature of the legislation is that no action at law may be brought against the Commission or against its agents without the special consent of the Attorney General of Ontario. The Commission is given unusual power of eminent domain, permitting it to enter upon the property of anyone without any preliminary proceeding, or authorization whatever, adjustments to be made later by an evaluator appointed by the Lieutenant Governor. The relations of the Commission with municipalities purchasing power for local distribution is somewhat involved since it gives considerable authority to the Commission over the activities of a local group. Hydro is the third largest public utility in Canada, having a capital of about $285,000,000, exceeded only by the Canadian Pacific and the Canadian National Railways. All accounts are audited by independent auditors appointed by the provincial government. All revenues to support the undertaking must come from the sale of power and rates are set on the principle that service is furnished at "cost" where cost includes a sinking fund to liquidate the capital, a renewal reserve to replace the system in 25 years, and all expenses of operation and maintenance. Similar careful financing in the local municipalities has led to a rather stable financial status. An elaborate bookkeeping system assesses against each municipality served the proportional amount of cost, including the cost of transmission. Funds for construction work are provided by sale of bonds or through funds borrowed through or from the Provincial Treasury.

The Commission has been able to maintain a staff of technicians and an extensive laboratory, and a certain amount of research work is usually under way. Thorough analyses are made of all constructions, designs, and materials so that their work has been well protected from technical mistakes. On the business side, the Commission has not been quite so fortunate. Following the death of Sir Adam Beck in 1925, certain contracts were made for the purchase of power from private companies in larger quantities than could be used, payments for which threatened the Commission with disaster and required cancellation of these contracts by the legislative assembly in order to avoid bankruptcy. This illustrates one weakness of public organizations of this type in which administrative authority is placed in persons whose own capital and interests may really be elsewhere.

The possibility of satisfactory administration of transmission networks as a federal function has been encouraged also in this country by the success of the British experience

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with what is commonly called the "British Grid" administered by the Central Electricity Board, known as the C.E.B. Beginning 20 years ago, our British friends spent nearly 10 years considering the problem of reducing coal consumption by substituting high-grade modern steam plants for some 500 old and small industrial and public generating stations. These had grown up supplying individual industries or very small districts with a multitude of frequencies and voltages and the condition was rapidly becoming worse with continuing high coal consumption and legal limitations against the combination of small districts into larger ones.

Finally, in 1926, the C.E.B. was established with considerable arbitrary power to build transmission systems, purchase the entire output of modern generating plants, and sell power to industries and communities at rates which have brought about the closing down of a few hundred old-fashioned stations. The organization and administration of the British Grid is involved in such a greatly different legal setup from ours as to make it impossible in this summary to give a worth-while comparison with the conditions in the United States. The Grid has met with considerable success and has over 3,000 miles of 132-kv lines covering most of the island. With sound management, they can hardly fail to be a success due to the great difference in economy between the old-style small steam plant and modern practice. There are problems still existing but they are being worked out and the C.E.B., which resembles in most ways an American corporation, seems likely to be of vast usefulness to the English communities and industrialists.

The most ambitious undertaking by the United States of the type under consideration is the Tennessee Valley Authority, familiarly known as the T.V.A. The T.V.A. Act established a corporation with the purpose of maintaining and operating United States property, to aid agriculture and industries, and to control floods and contribute to the national defense in the valley of the Tennessee River. The authority is vested in a board of 3 directors appointed by the president and subject to recall only by joint action of House and Senate. This board hires all employees without civil service limitations, is to pay prevailing wages, and has the usual corporate power to sue and be sued, make contracts, etc., is given the power of eminent domain to be exercised in the name of the United States, and is authorized to construct dams and reservoirs needed to complete and maintain a 9-foot channel to Knoxville with appertinent power plants and transmission system. It may produce, distribute, and sell electric power and go into the phosphate- and nitrogen-fertilizer business. Power is to be furnished for navigation locks free, and the surplus sold with preference for public groups of users. They may limit the rate schedules of any privately owned distributors to whom power is supplied, or cancel their privilege to buy. Earnings go to the United States Treasury, except for maintaining a continuing fund of one million dollars for operating capital. Any works on the river proposed by other parties are subject to approval by the T.V.A. Board.

The approaching completion of the construction work at Bonneville and the rapid progress at Grand Coulee, both on the Columbia River, add to the interest in a suitable plan for federal administration. Each new plant and each new region entered brings up new conditions and indicates an added need for flexibility in any scheme under which these utilities are to be operated. Every effort is being made to ensure that the benefits accruing from them shall be widely distributed.

Under authorization of the National Resources Committee, a thorough study of the Pacific Northwest and its resources was made during 1935 by the Pacific Northwest Regional Planning Commission made up of the heads of the planning boards of the 4 Northwest states, under the chairmanship of Marshall N. Dana, of Portland, Ore. This Commission, with the co-operation of a consulting staff of some 25 members, presented among other things recommendations for the administration of federal power in the Columbia Basin. These recommendations are based on the results of many hearings and consultations held throughout the region and represents closely the consensus of the Pacific Northwest opinion. These recommendations include: first, that federal construction work, including Bonneville and Grand Coulee, should be continued under the present departments, Bonneville being under construction by the engineers of the United States War Department and Grand Coulee by the United States Bureau of Reclamation. Much praise for the work of these 2 departments has been expressed by those familiar with their work on these projects. So since the operation of Bonneville will be associated with the operation of the lock in the Columbia and since a substantial portion of the power at Grand Coulee is to be used for irrigation pumping at Grand Coulee Dam, it is also recommended that the operation of these 2 plants be left permanently with the departments constructing them.

Second, the disposal of commercial power from Bonneville and Grand Coulee should be considered as a separate undertaking and placed in the hands of a new and separate agency. This power agency should have the form of a public corporation with the financing and other power usually accorded to such bodies. Its board of directors should be made up of 3 or 5 members to be appointed by the president with the approval of the Senate. One of these directors should be qualified for administration and management of the power system, another with special qualifications for planning, development, and promotion, and the third to have special qualifications in public relations and in the fields of social and economic development. If 5 are named, one might be at the suggestion of the Secretary of Interior and one by the Secretary of War, these probably to serve as part-time advisory directors. The following functions and powers should be entrusted to this power agency:

1. Major transmission lines, planning, designing, construction, maintenance, and operation.
2. Interconnection plans.
3. Interchange and dispatch of energy and its measurement.
4. Design of power facilities (including the review of any such designs carried out by other federal constructing agencies).

5. Development of power markets.

6. Specific planning for the further extension and development of its power system.

7. Sale of power at wholesale from points on its transmission system with contractual requirements that will insure that rates to the consumer pass on the economies in generation and transmission. With due respect to the interests of other agencies, the power agency should be given power to specify the maximum resale rates of any distributor which buys all or a major portion of its electric energy from the power agency.

8. Co-ordination and control of power production at federal power plants.

9. Regulation of release of water from federal storage reservoirs subject to state rights and irrigation needs.

10. The power agency should be authorized to interchange power with other agencies.

The power agency should be endowed with the accessory and usual powers, rights, and obligations of a corporation necessary to the exercise of the functions named. Initial federal financing should be provided and the obligation to contribute to state tax funds in proportion to the levies which are made upon similar private enterprises should be recognized. Public and nonprofit agencies should be given priority in the purchase of power and the power agency should be given the right of eminent domain as to purchase and lease of property useful in its operations. It should have the right to make contracts, to sue and be sued, and to conduct itself otherwise as a corporate autonomy. The agency should also be authorized to carry on research and experimentation to widen power utilization and markets and should be responsible for all recommendations as to future federal multiple purpose projects within the Basin.

The first official attempt to crystallize Northwest opinion into law was introduced May 12, 1936 as Senate Bill No. 4695, by the 4 Senators of Oregon and Washington and was analyzed and reported on by the committee on commerce, Report No. 2280. As finally presented it places the Bonneville plant construction, maintenance, and operation, and later installation of remaining machines, under the Secretary of War, through the chief of engineers. They also control the sale of power subject to approval by the Federal Power Commission. The War Department also is authorized to construct, operate, maintain, and improve transmission lines and related facilities. Navigation has first claim on the power; district and municipal organizations organized to serve rather than for profit come next. Within limitations surplus power may be sold to commercial operating companies. Contracts may be made for not to exceed 10 years but may give preference for an additional 10 years.

The War Department may purchase or condemn any or all real and personal property (including any existing electrical facilities) necessary to carry out the act. All receipts go to the United States Treasury. The Federal Power Commission may fix and revise rates without regard to existing statutes, rates to be based on costs.

The president may designate a federal agency to handle everything here assigned to the United States Engineers. This bill was brought up for consideration but failed in passage before the adjournment of the 74th Congress.

The first bill of the 75th Congress, dealing with power on the Columbia, was introduced by Representative Smith of Washington on January 5, H.R. 92. This bill placed the development of the plant at Bonneville and the building of transmission lines in the charge of the Secretary of War. The sale of power, also, was to be handled by the engineers of the War Department, but with almost every detail of power policy and, to some extent, contracts subject to the approval of the Federal Power Commission. The bill did not find satisfactory support and aroused considerable objection since it implied a control of rates at Boulder Dam. Largely, I believe, on this account this bill has been superseded by Mr. Smith's bill of February 19, 1937, when he offered House Bill No. 4948 incorporating what he stated were the desires of the President for control of power in the Northwest. The bill is to authorize maintenance and operation of the Bonneville project for navigation, flood control, and other purposes. The bill would leave completion of construction of Bonneville to the Secretary of War and also reserves to the Army Engineers, the operation of the lock which is to permit ocean boats to proceed upstream about 45 miles to The Dalles. Otherwise, the administration of operation, maintenance, sale of power, and promotion is to be by a Columbia River Administrator appointed by and responsible to the Secretary of the Interior. The Administrator is to act in consultation with an advisory board composed of 3 representatives, one to be designated by the Secretary of War, one by the Secretary of Interior, and one by the Federal Power Commission. This form of administration for Bonneville is stated to be intended as provisional until the establishment of permanent administration of Bonneville and other federal projects in the Columbia River Basin. The Administrator is authorized to operate, maintain, and improve Bonneville and related facilities, and is directed to carry on primarily for the purpose of promoting navigation and controlling floods, which, by the way, are 2 matters practically beyond his power. So far as consistent with these and to prevent waste, he shall add and improve machines and facilities for generation and transmission of such power as may be saleable. He shall encourage use of energy, construct, operate, maintain, and improve transmission lines and appurtinences to bring Bonneville's power to markets, existing and potential, and is authorized to interconnect with other federal projects and private or other public systems for exchange and emergency service. Public and co-operative agencies are to be given preference in purchase of power and half of the firm power available is to be held for them until January 1, 1939. Rates are to be approved by the Federal Power Commission. Contracts are to be made on a wholesale basis, except that sale may be made direct to large consumers. No contracts for more than 20 years may be made and these are to be subject to rate readjustment at ntervals of not over 5 years. Sales to privately owned agencies may be cancelled on 5 years notice if the power is needed for public agencies. Contracts with private companies for resale may contain stipulations concerning resale rates in order that the consumer may be protected. Rates are to be fixed with a view to

encouraging use but are to consider costs of generation, transmission, and amortization of capital investment over a reasonable number of years, the power to bear its fair share of the total cost of Bonneville. Except in emergencies, bids are to be called for on all items amounting to more than $500, but the Administrator may use usual business discretion in awarding contracts to responsible parties and in judging the materials offered.

The Administrator is to report to Congress each year. He appoints his own lawyers, engineers, and other experts and fixes their salaries, and appoints others under civil service rules.

All receipts are to go to the United States Treasury, except an operating fund of $500,000. Authorization of appropriations necessary to carry on is included. The Administrator, in the name of the United States, may bring suits and, by implication, may be sued.

On April 14, 1937, Representative Walter M. Pierce of La Grande, Oregon, introduced still another bill for establishing a suitable administration for Bonneville. He would place an administrator in full charge of both generation and distribution and make him responsible solely to the Secretary of the Interior, except that rate schedules and revisions become effective after approval by the Federal Power Commission. This places the responsibility for operation of the Bonneville plant for power production in the hands of the Administrator subject to completion of construction of the plant, including locks, fishways, power, and appurtinences and the continued operation of locks and fishways only by the United States Engineers under the Secretary of War. This administration is to be provisional, pending the establishment of permanent administration for Bonneville and other projects in the Columbia River Basin. The authority carries with it the right to condemn property, franchises, etc., needed for carrying out the purpose of the act and the preferential rights of public nonprofit bodies domestic and rural consumers, is carefully guarded through reservation of 50 per cent or more of the energy until January 1, 1941, for such nonprofit bodies, provided, however, that such energy reserved but not actually purchased by nonprofit groups prior to January 1, 1941, may be disposed of temporarily to any purchaser. The Administrator is further authorized to contract for interchange of power with any other system as mutual emergency protection of service. The Administrator is also instructed to consult and co-operate with nonprofit groups within economic transmission distance of Bonneville in order to assist them in securing their privileges. In other ways the bill closely resembles other earlier measures.

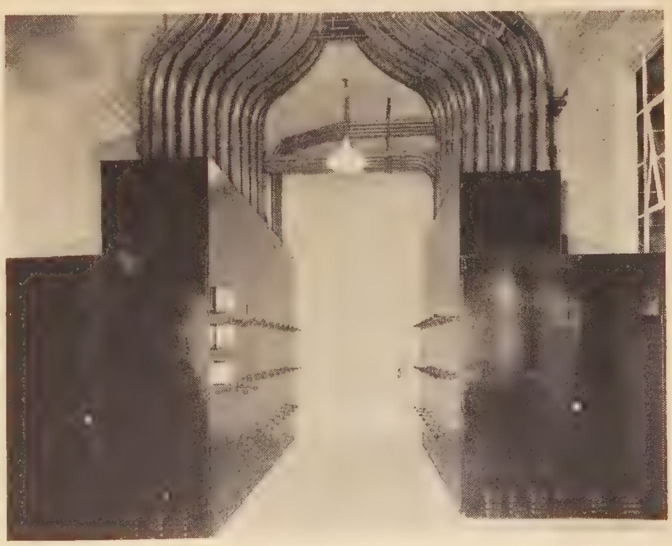
This bill by Representative Pierce is based to some extent upon the recommendation of President Roosevelt, dated February 24, in which he approves the progress report of the President's Committee on National Power Policy. The recommendations of this committee are quite closely followed by Representative Pierce, except that the Committee advises that the Administrator should act in consultation with an advisory board composed of representatives designated by the Secretary of War, Secretary of the Interior, and the Federal Power Commission. Included in the Committee's statement is:

> "In computing the cost of electric energy developed from water power created as an incident to the construction of Bonneville project for other purposes, there may be allocated to the cost of electric facilities not simply the cost of such facilities, but also such a share of the cost of facilities having joint value for the production of electric energy and other purposes as the power development may fairly bear as compared with such other purposes. The rate schedules may provide for uniform rates or rates uniform throughout prescribed transmission areas with a view to distributing the benefits of an integrated transmission system and encouraging the equitable distribution of the electric energy developed."

Since power will be available at Bonneville before the end of 1937 early action is important. This is true not only to conserve a national asset but to enable the public utilities of the Northwest to determine their program for ensuring a sufficient power supply. They have operated all available steam plants most of the time in recent months and must build or buy power to prevent a serious shortage within the next few months.

Compact Distribution Center

Westinghouse Photo



FIFTY-TWO distribution circuits are concentrated in this switchboard recently installed in a Philadelphia, Pa., industrial plant. Dead-front air-break circuit breakers are used throughout. On the left is a 440-volt 3-phase 60-cycle power-distribution switchboard supplied from 3 500-kva stepdown transformers, which has 30 400-ampere distribution-feeder breakers with 7 submetering current transformers and watt-hour meters. The switchboard on the right is for lighting distribution, and has 22 300-ampere circuit breakers for the 3-phase 4-wire grounded-neutral system, which is supplied with 120 and 208 volts from 3 333-kva transformers. Each circuit breaker controls a main feeder circuit to a definite plant section.

The Ultrahigh-Speed Reclosing Expulsion Oil Circuit Breaker

By A. C. SCHWAGER
MEMBER AIEE

DURING the last few years, the problem of increasing the continuity of service of electric transmission systems has been given considerable study. Of all the proposals by which it is intended to bring about a reduction in outages, the practice of ultrahigh-speed reclosing of oil circuit breakers gives promise of the most effective and most economical solution.

The advantages of automatic-reclosing circuit breakers have been known for a long time and records are available showing that approximately 90 per cent of all outages can be eliminated during the first opening followed by reclosure. This value was first determined for a reclosing interval of 15 seconds but later confirmed for immediate reclosure.[1]

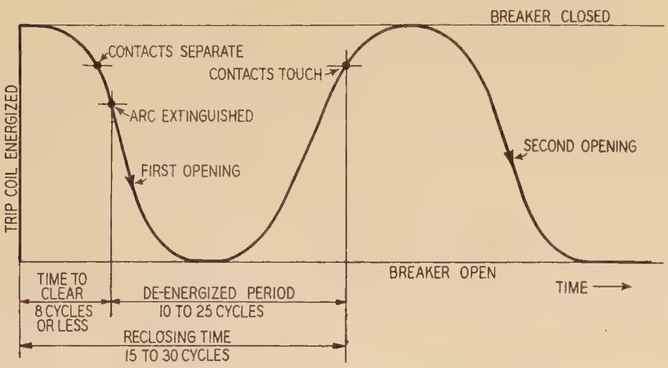


Figure 1. Travel-time chart of ultrahigh-speed reclosing breaker

"Immediate reclosure" in the above sentence defines operations in which the interval from trip coil energized to circuit reclosed amounts to from 30 to 80 cycles, the lower value applying to lower, the upper limit to higher voltages.

It is obvious that additional advantages could be obtained by reducing the reclosing interval still further. A reduction to from 15 to 30 cycles would in many instances prevent the loss of synchronous equipment load and would in general eliminate the remaining disadvantages of outages of too long a duration.

Figure 1 shows a travel-time chart of the reclosing cycle taking place within the above-mentioned periods. The term ultrahigh-speed reclosing has been previously applied to this type of operation and will be used in the following.[2] The de-energized period according to figure 1 amounts to from 10 to 25 cycles. This is sufficient time to allow the dielectric strength of the fault path to recover to such a degree as to withstand reapplication of line voltage, provided that the short circuit is due to the most common causes such as insulator flashover or line swinging.

In designing an oil circuit breaker which will meet the specifications outlined in figure 1, the manufacturer is confronted with the following 2 major problems:

1. Develop an operating mechanism which will meet the specifications as to mechanical performance, when applied to present designs of breakers.

2. Assure the behavior of the rupturing devices under immediate reclosing conditions. Although a great deal of interrupting capacity test data on modern breakers is available, information on 2 successive interruptions within an interval of a few cycles is lacking. If possible, tests should be carried on with time intervals smaller than those employed in service.

Problem 1—Operating Mechanisms

For a considerable period of time, the solenoid control represented the standard design of operating mechanism. With the demands for shorter opening and closing times, spring-actuated motor-wound mechanisms were developed and during the past 10 years have found a great field of application. In addition to increased operating speeds, they had the advantage of requiring small operating currents, in many instances eliminating the necessity for expensive batteries. These controls provide stored energy for one closing and one opening operation of the breaker. Rewinding of the springs occurs immediately after the opening stroke and in general requires several seconds. It is obvious that in spite of the above-mentioned advantages this latter type of control is not suitable for immediate reclosing.

The conventional solenoid control was, therefore, re-

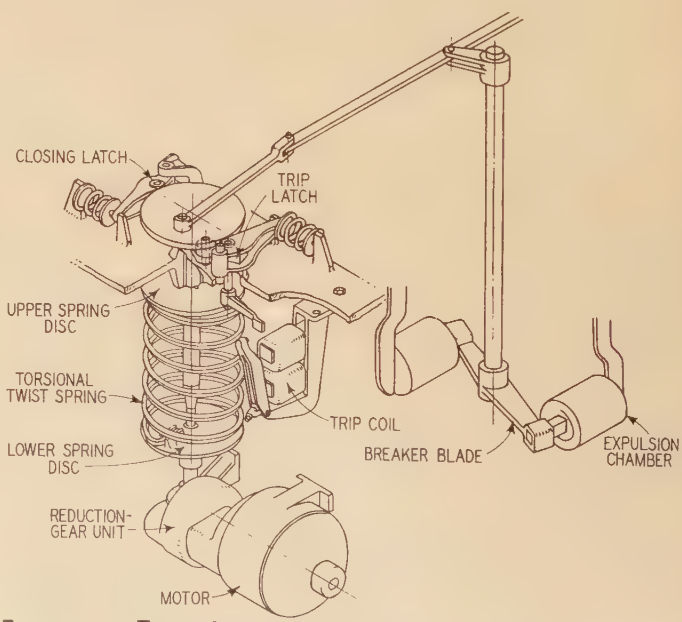


Figure 2. Typical arrangement of motor-wound spring-actuated reclosing mechanism

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1. For all numbered references, see list at end of paper.

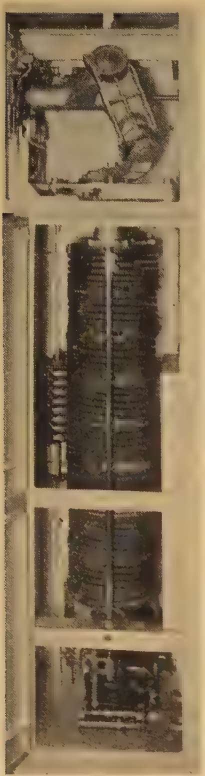


Figure 3. Fast-reclosing operating mechanism for 69-kv breaker

considered with a view to improving its performance to comply with the specifications contained in figure 1. No difficulty was encountered in meeting high speeds in opening, which is generally accomplished by springs. In closing, however, the upper limit of the specifications was not even approached. This is due mainly to the fact that an excess of time is lost in accelerating the heavy plunger. A combination of 2 prewound motor controls would, of course, solve the problem in an academic way, but it does not seem feasible economically and introduces complications due to the presence of double closing and trip coils. The problem was, therefore, attacked on a more fundamental basis along the following lines of thought.

Some type of motor-wound spring-actuated mechanism, designed to produce the required operating cycle with the least number of parts and in a thoroughly reliable manner seemed preferable. The mechanical design should be such as to produce the greatest possible speed and shortest operating time. The simplest mechanism is one which incorporates only one spring to perform the entire cycle of opening, closing, and opening.

A control of the type shown in figure 2 seems to meet the above specifications in the most direct manner. It is shown applied to a conventional rotary-type oil circuit breaker, although it is equally suitable for the drop bar type and has been developed for breakers from 7.5 to 138 kv. A reduction-geared motor winds up a torsional twist spring. Suitable closing and tripping latches retain and release the upper spring disk. A motor limit switch is provided which rewinds the spring automatically to a predetermined torque whenever an operation of the breaker has released part of the spring energy. Although the length of the spring is chosen to give one immediate reclosing cycle it is possible to meet possible future requirements for more than one immediate reclosure by lengthening of the spring. The motor is of such size that the spring is wound for additional time-delayed reclosure in an interval smaller than that available in the conventional automatic reclosing timers. Figure 3 shows a control of this type as applied to a 69-kv breaker. The simplicity of the design is apparent, the essential parts such as motor and spring constituting the major portion of the mechanism. In the particular case shown the unidirectional rotary motion of the upper spring disk is transformed into a reciprocal radial motion of the horizontal breaker operating shaft by means of a bevel link.

Table I

Test Number	Amperes (Root-Mean-Square)	Voltage Across Breaker (Root-Mean-Square Kilovolts)	Time to Clear. Trip Coil Energized to Arc Interruption (Cycles)	Reclosing Time (Cycles)	De-energized Period (Cycles)
1	400	12.3	5.3	11.3	6.0
2	920	12.3	5.3	11.3	6.0
3	1,800	12.3	5.1	10.8	5.7
4	2,600	12.3	5.0	11.5	6.5
5	3,760	12.3	5.5	10.2	4.7

Problem 2—Interrupting-Capacity Tests

In order to satisfy the questions brought up under the heading of the second problem, the need for an analysis of the arc-interruption phenomena within expulsion chambers during quickly repeated interruptions was indicated.

The expulsion-chamber arc-rupturing device consists essentially of an explosion chamber which is vented in a direction opposite to the direction of opening the blade. The gases produced during interruption, therefore, escape into

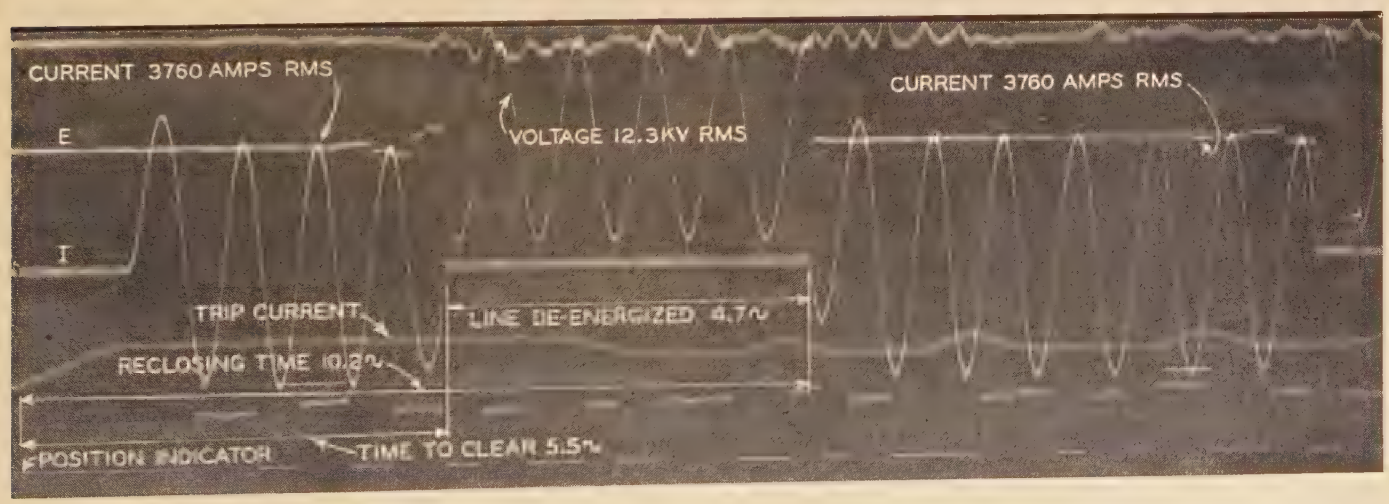


Figure 4. Oscillogram of interrupting-capacity test on 15-kv expulsion breaker and fast reclosing control

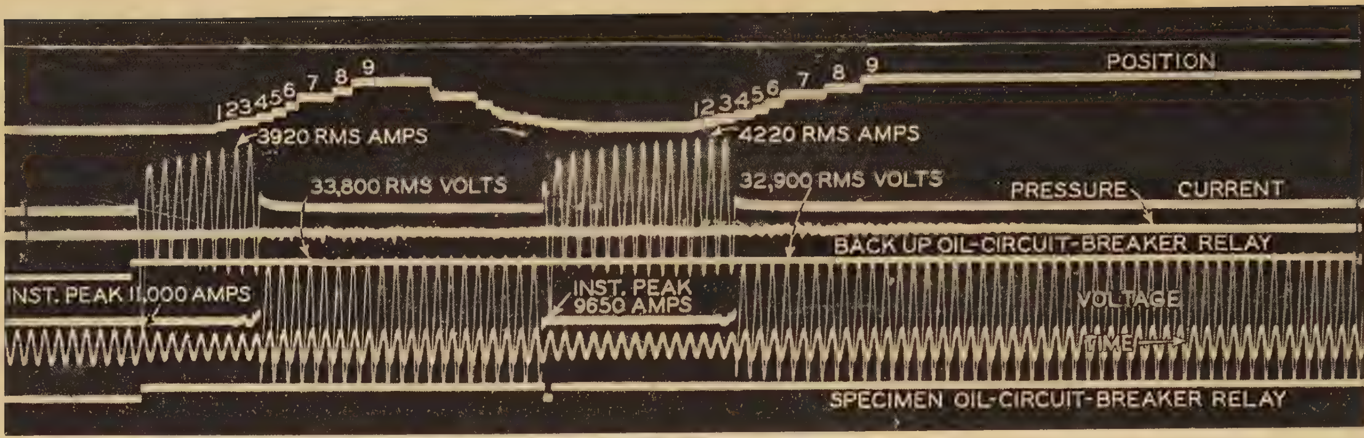


Figure 5. Oscillogram of 69-kv field interrupting-capacity test on expulsion breaker operated by means of ultrahigh-speed control

a space remote from that in which the blade opens. Contrary to many other modern arc-rupturing devices, no contamination of the major break path takes place, a fact which allows the accomplishment of a large number of successive rapid interruptions without any loss in effectiveness of the expulsion chamber.

For the purpose of interrupting capacity tests the control shown in figure 2 was connected to a single phase of a 15-kv expulsion circuit breaker. In this manner the smallest time interval between 2 successive interruptions was obtained. The results are shown in table I.

Table II

Cause of Interruption	Fault Cleared After Immediate Reclosure	Fault Not Cleared After Immediate Reclosure
Lightning	27	2
Birds	4	
Insulation	1	1
Unknown	1	

Interruption occurred in all cases without disturbance, without oil throw and without noticeable tank pressure. The arcing times for the first and second opening were substantially the same. The suitability of the expulsion chamber for ultrahigh-speed reclosing operation is, therefore, established for intervals in the order of 10 cycles. Figure 4 shows an oscillogram of the interruption corresponding to test 5, table I.

Field Tests

A 69-kv expulsion oil circuit breaker equipped with the ultrahigh-speed reclosing control shown in figure 3 was given a field test to determine operation under immediate reclosing duty. Generating capacity of 75,000 kw was available at the test location, and an additional 90,000 kw capacity was feeding from remote sources into the short circuit. As shown on oscillogram figure 5, the equivalent 3-phase short circuit amounted to 400,000 kva during the first opening and to 420,000 kva during the second opening, the reclosing and de-energized period being $28^1/_2$ cycles (including relay time) and $19^1/_2$ cycles, respectively.

Field Experience

The 69-kv breaker reported on under field tests has been in continuous operation since February 29, 1936; it protects a single-circuit 60-kv line, 113 miles long which is subject to severe lightning conditions. Up to December 31, 1936 the breaker was called to clear 36 short circuits, in 33 cases the fault was eliminated by means of the immediate reclosure and only in 3 cases did the breaker trip out a second time. Table II shows the causes of the short circuits.

It is hoped that additional field experience will soon be available on a reclosing breaker recently installed on a 115-kv tie line.

Conclusion

An extremely simple motor-operated spring-actuated operating mechanism, suitable for ultrahigh-speed reclosing has been developed. In conjunction with expulsion oil circuit breakers it has been shown to provide an ideal means for immediate re-energizing of transmission systems. A 90-per-cent reduction in outages, previously reported by others is confirmed on an additional system. From limited experience the exact field of application cannot be completely defined, but indications are that ultrahigh-speed reclosing circuit breakers of this type will become more and more common. The simplicity of design of the mechanism gives promise of its use as a standard operating means, and if at a later date ultrahigh-speed reclosing is desired, but a slight change in wiring and instruments is required.

References

1. Automatic Reclosing of Oil Circuit Breakers, A. E. Anderson. Electrical Engineering, volume 53, January 1934, pages 48–53.

2. Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines, Philip Sporn and D. C. Prince. Electrical Engineering, volume 56, January 1937, pages 81–100.

Radiotelephone Noise Reduction by Voice Control at Receiver

By C. C. TAYLOR
MEMBER AIEE

Introduction

IN TRANSMITTING speech over radiotelephone circuits there are a number of conventional methods of increasing the signal with respect to the noise. Examples of such methods are the use of higher power, directive antennas, diversity reception, and filters to narrow the received frequency band. In addition, there are other methods of a special character which reduce the effect of the noise interference with the speech transmission. One example of such a device limits the noise interference by eliminating the high peaks of noise of very short duration and depending upon the persistence of sensation of speech in the ear to bridge the gaps. Another method diminishes the noise in intervals of no speech. This is the method which will be discussed here.

Speech and Noise Considerations

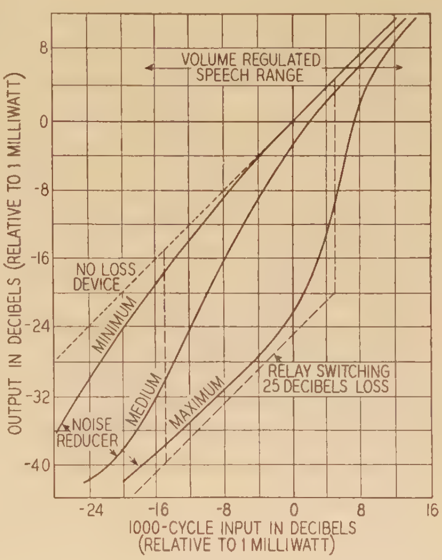
Speech signals may be represented by a group or band of frequencies occupying a certain interval of time. In using the conventional method of narrowing the received frequency band, filters eliminate all noise outside the band actually required. In fact we sometimes go beyond this and remove some of the outer frequency components of speech which are weak and submerged in the noise and therefore contribute little or nothing to the intelligibility. Experiments have shown the effect on voice transmission of removing portions of the frequency range.[1] Articulation tests were used to afford a quantitative measure of the recognizability of received speech sounds. These show that the upper frequencies may be cut off down to about 3,000 cycles without serious reduction in articulation. After such treatment, as the noise level increases, the weaker and less articulate sounds become more and more submerged in the noise and additional reduction in the detrimental effect of the noise is required.

In addition to the speech waves covering a frequency band they occupy intervals of time. The unoccupied intervals between the speech sounds contain noise. Reduction of the noise reaching the ear in these intervals has been found to result, under certain conditions, in an improvement in speech reception. This may possibly be explained by considering the characteristics of the ear.[1] It has been shown that noise present at the ear has the effect of shifting the threshold for hearing other sounds or has a deafening effect. That is, there is a reduction of the capacity of the ear to sense sounds in the presence of noise. For example, if a person has been listening to a noise for a certain period, his ear is made insensitive so that speech signals following are not so easily distinguished. The ear has a sensory build-up time, that is, a time needed for the noise to build up to a steady loudness. By reducing the noise in the intervals of no speech the average threshold shift seems to be diminished. Aside from this the presence of the noise tends to distract the attention from the perception of the speech. Removal of noise during the intervals of no speech tends to reduce this effect.

Requirements

In considering the elimination of the noise during these intervals it is necessary to bear in mind certain characteristics of speech.[2] Speech waves may be regarded as nonperiodic in that they start at some time, take on some finite values and then approximate zero again. In connected speech it is usually possible to approximately distinguish between sounds and to ascribe to each an initial period of growth, an intermediate period which in some cases approximates a steady state and then a final period of decay. The duration intervals of various syllabic sounds vary from about 0.03 to as much as 0.3 or 0.35 second. When noise is high the weaker initial and final sounds become obscured so that they contribute little to the intelligibility.

Figure 1. Input-output comparison of noise reducer and voice-operated relay



In connected speech, silent intervals occupy about $^1/_5$ to $^1/_3$ of the total time. Also there are frequent intervals when the sounds are rather weak. However, if we attempt to suppress noise during all these intervals, experi-

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1. For all numbered references, see list at end of paper.

ence shows that the suppression becomes too obvious, and the speech is apt to sound mutilated. For this reason the function of any device to be used for reduction of noise in the intervals between speech is to operate rather quickly to remove suppression and pass the speech and approximately to sustain this condition for sufficient periods to override weaker intervals so that obvious speech distortion does not occur.

To reduce the noise in the intervals between speech it is necessary to depend for control upon either the speech

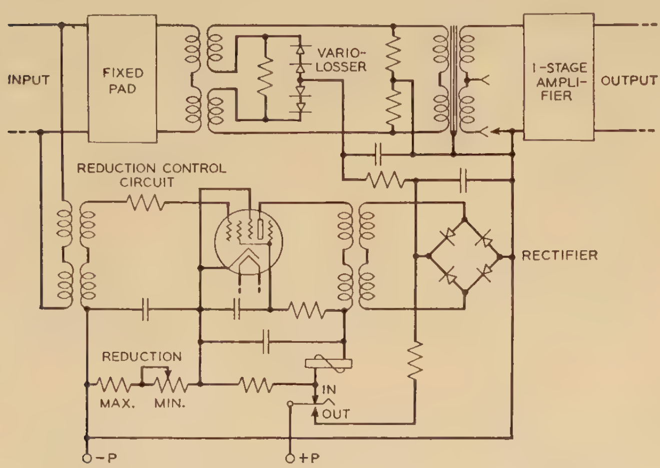


Figure 2. Simplified schematic of noise reducer

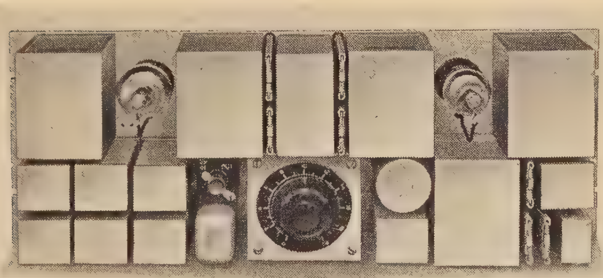


Figure 3. Noise reducer panel

itself or upon some auxiliary signal usually under the control of the speech at some point in the circuit where the signal-to-noise ratio is better. This latter condition is illustrated on a circuit where the carrier is transmitted only during speech intervals. The carrier then acts as an auxiliary signal which operates a device at the receiver to remove loss.[3,4] The device to be discussed below utilizes the speech itself at the receiver to perform this function.

In using the speech in this way it is obvious that control can only be accomplished when the speech energy sufficiently exceeds the noise energy so that the presence of the speech is distinguishable. The device could operate abruptly as, for example, a relay which removes a fixed loss in the operated position and restores it when nonoperated. Experience indicates that the use of such a device makes the suppression too obvious if it is to follow the speech sounds closely. It is desirable, then, to perform this reduction by more or less gradually removing loss as the speech increases to accentuate the difference between levels of speech sounds and levels of noise which occur in the gaps between speech.

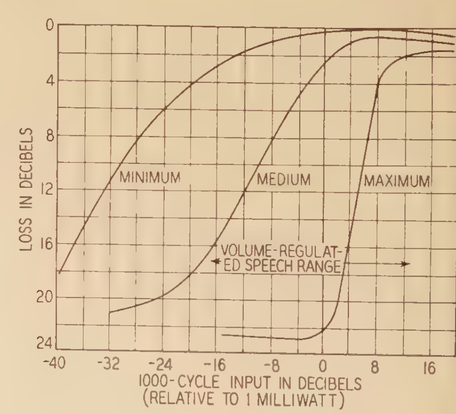
Noise Reducer

This kind of performance has been secured in a device known as a noise reducer. A comparison of the action of the noise reducer and a relay having similar maximum loss is shown in figure 1. This figure shows the input-output characteristics of these devices over the voice amplitude range to which they are subjected on a radio circuit. The noise reducer may be likened to a relay with a variable loss, the loss not varying instantaneously but over a short period of time. The loss, for any short period, may be any value within the loss range and the device has, therefore, been likened to an elastic or shock absorbing relay.

The noise reducer has no loss for strong inputs, considerable loss for weak inputs and changes this loss gradually over a short interval of time. It introduces loss in the absence of speech but reduces this loss in proportion to the amplitude and duration of waves impressed upon it. The time required for the loss change is such that abruptness of noise change is absent and very short impulses of static do not effectively control the loss. This contrasts with a very fast limiter acting on high peak crashes only.

The noise may control the loss if its average amplitude is strong enough. Therefore, the control is made adjustable so that the noise waves are not permitted to control for any noise condition within the range of usefulness of

Figure 4. Loss versus input for several settings of the reduction control



this device. Thus the noise in the absence of speech is always reduced and the portions of the initial and decay periods of the speech sounds which are also reduced vary with this adjustment for noise intensity. Of course, if the speech-to-noise ratio becomes too small or if other transmission conditions interfere, an improvement becomes impossible.

Circuit Arrangement

Figure 2 shows the circuit of the noise reducer in simplified schematic form.[5] Incoming waves pass from left

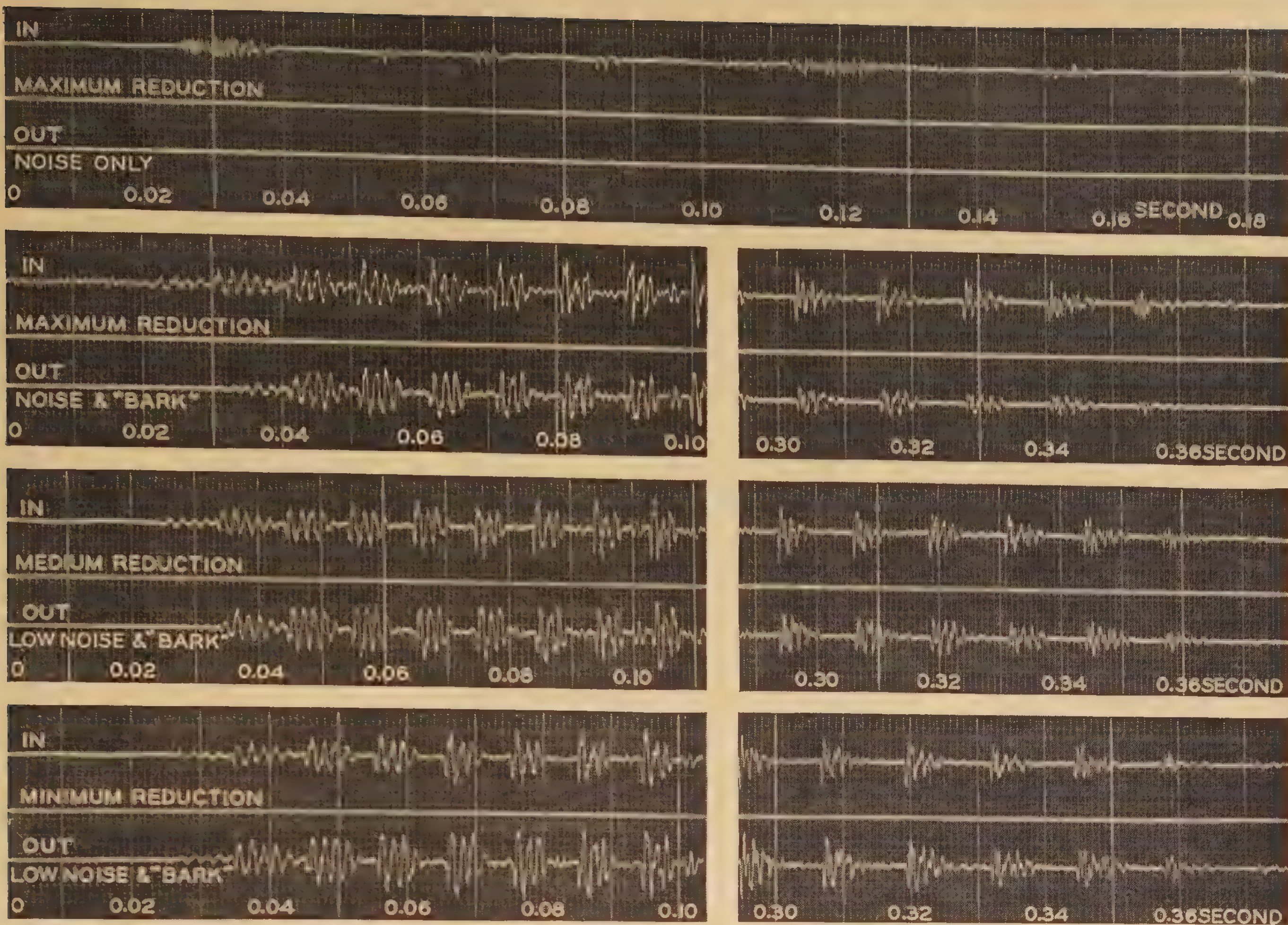


Figure 5. Input and output for (top to bottom): high noise with maximum reduction; high noise with the beginning and ending of the word "bark"—maximum reduction; low noise, the word "bark"—medium reduction; low noise, the word "bark"—minimum reduction

to right through the fixed pad, the vario-losser and the amplifier to the output. At the input, part of these waves pass through the reduction control branch circuit which includes a variable resistor, an amplifier, and a rectifier. The direct current produced by the rectifier is applied through the condenser and resistance filter to the copper-oxide losser circuit. For current below a threshold value, no appreciable change occurs in the losser and the loss introduced is about 20 decibels. As input increases, rectified current reaches a value where the loss begins to change rapidly. It becomes zero decibles at an input about 20 decibels above the point at which the loss starts to change. The design is such that the loss remains substantially constant for higher inputs.

The vario-losser makes use of the resistance variation with current of copper-oxide rectifier disks. This variable resistance shunts a fixed resistance in series with the windings of a repeating coil as shown in figure 2. The maximum loss is determined by the fixed resistance when small current is flowing through the disks while the varying loss is determined by the shunting copper-oxide resistance which decreases rapidly with increasing current above a threshold value until a low value is reached. The minimum loss is limited by the output of the control tube approaching a maximum and the shunting resistance becoming so small that additional decrease affects the loss inappreciably.

The variable resistor setting in the reduction control circuit determines the input amplitude at which reduction begins and therefore the point above which the loss remains substantially constant. If there is a difference in amplitude between speech and noise, the reduction control may be so adjusted that the noise on the circuit, when no speech is present, is appreciably reduced. The action then is as follows: In the absence of speech noise is reduced usually the maximum value of 20 decibles, during intervals of lower speech amplitudes the loss decreases in proportion to the increase in amplitude and during speech of high amplitude both noise and speech are transmitted without loss. As the noise encroaches upon the range of speech amplitude, it becomes necessary to reduce greater amplitudes, thereby also further reducing the weaker parts of speech.

The noise reducer is contained on a $7^1/_4$-inch panel for relay rack mounting. Figure 3 gives a front view. The panel contains the reduction control resistor and an "in-out" key which, in the "out" position, gives the device a fixed loss. Both resistor and key may be duplicated external to the panel with the wiring arranged to give remote control.

Characteristics

Figure 4 gives the 1,000-cycle input-loss characteristic for 3 settings of the reduction control. For any setting, there is an input volume above which the loss remains constant, while for volumes below this the loss increases with decreasing input until the maximum loss is reached. The volume-regulated speech range encountered on radio circuits at some point in the circuit which is 5 decibels above reference volume as measured on a volume indicator is indicated as extending from +13 decibels to −17 decibels referred to one milliwatt for the purpose of showing approximate corresponding speech amplitudes.

Figure 5 shows oscillograms giving the input and output characteristics of noise for maximum reduction and of speech for maximum, medium, and minimum reduction. The upper trace is the input and the lower trace the output. The middle trace is not used. It will be noted by inspecting the "in" and "out" traces at the beginning and ending of the word "bark" that there is some distortion in speech for the maximum reduction condition, but very little distortion for minimum reduction. Maximum reduction would be used only in case of high noise where this distortion is less objectionable than the noise.

Performance

Laboratory tests have been made in an attempt to evaluate the advantages to be gained by the use of the noise reducer. It was shown that, for the rather limited and controlled conditions which were tested, definite advantage can be observed in judgment tests of the effectiveness of speech transmission through noise with and without the noise reducer. This advantage is of the order of magnitude of 3 to 5 decibels at the border line between commercial and uncommercial conditions on the noisy circuit.

This figure is in approximate agreement with results obtained from records of performance on commercial connections. A curve is available which shows the approximate relation between percentage lost circuit time and transmission improvement for a long-range short-wave radiotelephone circuit.[6] From the records of lost circuit time as affected by the noise reducer use an improvement of 4 decibels is obtained from this curve.

Observations were made and records kept for 12 months of the use of the device at the land terminal of the high seas ship-to-shore circuit and for shorter periods on New York-London circuits. These observations indicate that the noise reducer most satisfactorily reduces objectionable effects where the interference consists of noise of a fairly steady character. As might be expected it is somewhat less effective on crashy static. If the noise is very low there is no improvement; as the noise increases the benefit increases up to a certain point; when the noise amplitudes begin to approach too closely the peak amplitudes of the voice waves it becomes impossible to distinguish between them without producing objectionable speech distortion and there is again no advantage. Where volume fading is present there is a tendency to accentuate the volume changes and it becomes necessary to adjust the reduction control to limit this. Otherwise this effect may offset the possible noise improvement. The operating practice is to adjust the reducer control circuit for each noise or transmission condition so that optimum reception as judged by the technical operator is obtained. The general rule is to use the minimum reduction possible.

Use of Noise Reducer With Voice-Switched Circuits

On radiotelephone circuits for connection to the land telephone system, control terminal equipment is used at the junction of the land lines and the 2 one-way radio channels (one transmitting, the other receiving) necessary for 2-way communication. In making this connection a widely used method is one in which the 2-wire land circuit is normally connected to the receiving radio channel and is switched to the transmitting channel when the land subscriber talks. This switching is done by voice operated relays.[7,8] The noise reducer in addition to improving the intelligibility of the speech protects these voice-operated relays against false operation by the received noise.

Figure 6 shows the application of the noise reducer to

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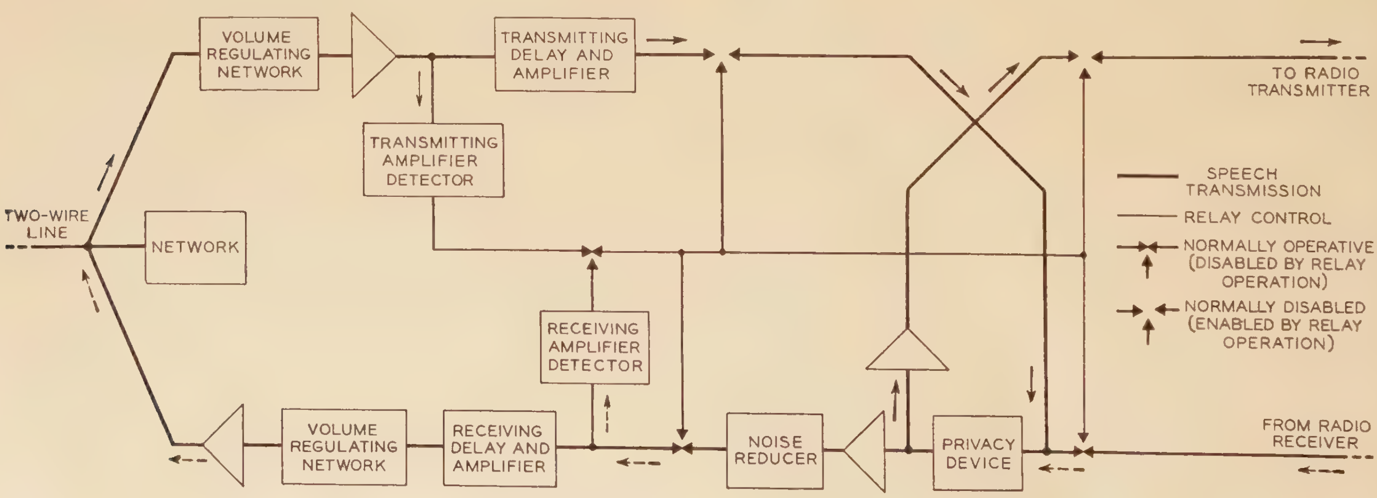

Figure 6. Application of noise reducer to radio control terminal

Analysis of Series Capacitor Application Problems

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Introduction

IN THE past several years series capacitors for the compensation of line drop in power circuits have found increasing use,[1–9] because improved and automatic voltage regulation can, in many cases, be obtained more economically by this method than by any other means.

Most of the applications have been entirely successful in improving the system performance. However in a few instances unforseen difficulties of an unusual character have been encountered. These difficulties were the occasion of a systematic and detailed analytical study of series capacitor performance. This study has been paralleled, as far as possible with laboratory tests and correlated with field experience. It is believed that a satisfactory explanation and understanding of the abnormal system behavior have now been obtained and that adequate methods for predetermining the system performance have been developed, although it is recognized that the investigation cannot be regarded as absolutely final and complete.

The objects of this paper are to present a survey of some of the troubles which may be encountered in the application of series capacitors to power circuits, to present criteria for determining the range and probability of abnormal operation, and to describe methods for minimizing the difficulties.

Three types of abnormality have been investigated:

1. Distorted and excessively large transformer exciting currents, due to saturation.
2. Hunting of synchronous machines.
3. Self-excitation of induction motors.

In case 1, the application of voltage to an unloaded or very lightly loaded transformer through a series capacitor may result in abnormally large and distorted exciting currents. These large currents are not simply transients but persist as a steady-state condition. This type of circuit, that is, a saturable inductance in series with a capacitor, has been found to have at least 2, and probably more, different steady states, depending on how the voltage is applied.

Solutions of the equations for this type of circuit have been found by the differential analyzer[10] at the Moore School of Electrical Engineering and are discussed in section I.

In case 2, interconnected synchronous machines will oscillate or "hunt," under certain circuit conditions. The tendency to hunt becomes more pronounced as the effective ratio of line resistance to line reactance increases, and putting in a series capacitor to decrease the reactance obviously increases this ratio. Consequently, if the machines are susceptible to hunting, the condition is further aggravated by the addition of capacitors. The case of hunting of a single synchronous machine operating from an infinite bus was investigated several years ago.[11,12] In section II of the present paper, further analytical methods are developed involving 2 or more machines which enable the size and location of a capacitor to be so chosen as to product the least tendency to hunt consistent with proper voltage regulation.

In case 3, under certain circuit conditions an induction motor operating with series capacitors will be self-excited and will generate other voltages of lower than normal frequency and thus produce objectionable voltage fluctuations. Analytical methods are presented in section III, which make it possible to determine the effectiveness of methods for eliminating this trouble.

It has been found in this investigation that the addition of a resistor in shunt with the series capacitor will eliminate the difficulties of cases 1 and 3, while the synchronous machine hunting of case 2 is minimized or not obtained by proper choice and location of the capacitor. The shunt resistor is of such a high value as not to interfere with the capacitor's effective operation as a line drop compensator and the value of the power loss in the resistor necessary to ensure complete freedom from these circuit troubles will in general be less than 10 per cent of the resistance loss in the line to be compensated. The proper value of resistance to be used in any given case may be determined from the analysis presented here. It is concluded, therefore, that the material offered in this paper, will enable practical and economically sound series capacitor applications to be made with confidence that the operating results will be in accordance with predictions.

Section I—Distorted and Excessively Large Transformer Exciting Currents

A. General

In the usual case of application of voltage to an unloaded transformer it is known that if the voltage is applied at or near the zero point of the voltage wave a high inrush current may result. This is because the transformer flux tends to rise, in the first half cycle, to double its normal value, with consequent excessive magnetizing current due to the very high degree of saturation. Stated in another

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1. For all numbered references, see list at end of paper.

way, at high values of flux the effective inductance of the transformer becomes very low. The high inrush current lasts for several cycles and then the transformer draws only its usual low value of exciting current. On the other hand, if the transformer is supplied through a series capacitor an abnormal current may persist in the steady state. That is, the energizing of an unloaded or very lightly loaded transformer through a series capacitor may result in a continuous abnormal flow of exciting current. This current may be equal to or even greater than full load current and is of an apparently very low frequency, resulting in a badly distorted current wave. Under this condition of excitation the secondary voltage is also badly distorted, and it likewise is largely composed of a lower frequency component. Oscillographic records of the magnetizing current, the secondary voltage and the voltage across the capacitor when a circuit is in this state of excitation are shown in figure 1.

These abnormal steady-state currents flow when the voltage is applied at or near the zero point of the wave just as the high transient occurs for this condition in the ordinary case without the series capacitor.

This phenomenon has been reported before[13–16] in the technical press and is sometimes called "ferro-resonance." The peculiar circuit behavior depends essentially on the nonlinear transformer characteristics and not on any secondary features such as hysteresis, eddy currents, etc.

The nonlinear characteristic of the transformer makes the mathematical analysis very difficult and to the authors' knowledge there has been no satisfactory analytical solution made as yet.

The differential analyzer at the Moore School of Electrical Engineering was used, with the able assistance of Irven Travis and C. N. Weygandt, to obtain solutions to the nonlinear differential equations of this circuit. Appendix *A* gives the equations of the circuit and the form into which they were put to adapt them to the analyzer.

The single-phase circuit, as shown by figure 2, was set up and investigated thoroughly before the 3-phase case was studied, as it was believed that the essential features of the phenomenon could be obtained more directly in this manner. A schematic diagram giving the analyzer set-up for equations 2*a* and 3*a* is shown in figure 3.

The 3-phase circuit was set up as a final check and the results obtained indicated that the single-phase results were qualitatively applicable.

Typical curves drawn by the analyzer as solutions to equations 2*a* and 3*a* are shown in figures 4, 5, and 6.

A short simplified explanation of the physics of the phenomenon will be made here, for the sake of completeness.

B. Qualitative Explanation of Phenomenon

These abnormal currents may be explained as follows: Consider that the voltage is applied to the transformer at the zero point of the wave. During the first part of the cycle the flux in the core builds up just as though the capacitor were not present, since the current drawn is so small that there is no appreciable voltage drop across the capacitor. However, as soon as saturation is reached, the current drawn becomes very large and a voltage soon appears across the capacitor. The voltage absorbed by the capacitor prevents the flux from building up to as high a value as it would have without the capacitor, so the first half cycle inrush current is somewhat less. Moreover, as the flux tends to remain offset it does not reach a high value in the negative direction in the second half cycle. To the contrary, it may hardly dip below zero. Thus the exciting current remains very small (or, the transformer inductance remains very large) for the interval following. The charge is therefore left on the capacitor, which simply acts as an additional voltage source. This additional voltage tends continually to depress the transformer flux, just as in the first half cycle it prevented the flux from reaching double its normal value. Thus in the second cycle the flux may not go high enough to saturate the core so no additional charge is put on the capacitor. On the other hand, as practically no charge has leaked off, the capacitor voltage is still decreasing the flux. The general effect is as shown in figures 4*b* and 4*c* and is that of first

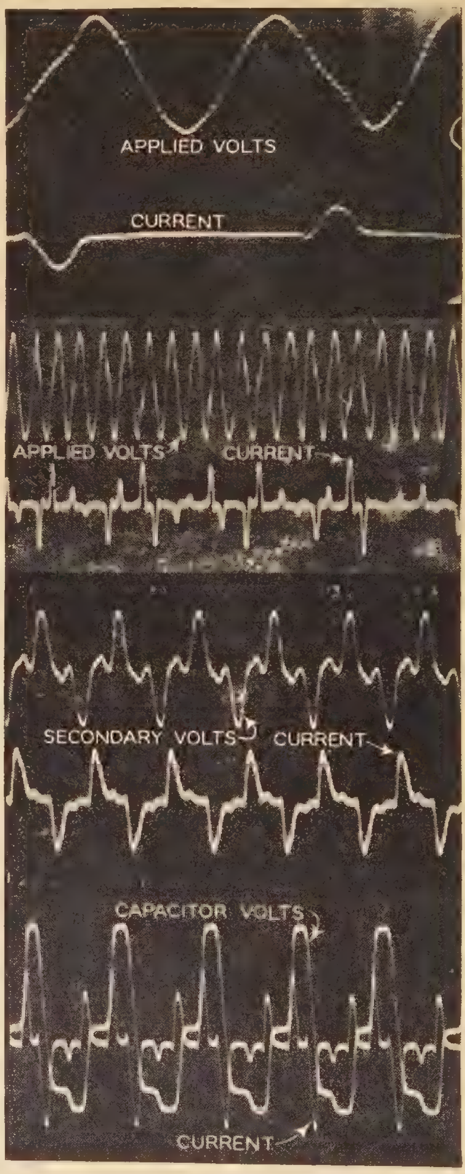
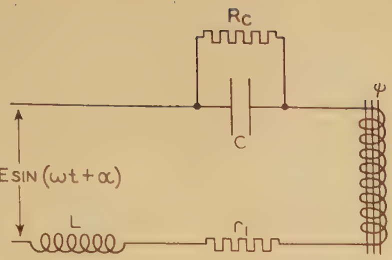


Figure 1. Oscillograms of abnormal currents and voltages obtained when transformer is excited through series capacitor

Figure 2. Circuit diagram of transformer energized through a series capacitor, series impedance, and shunting resistance R_c



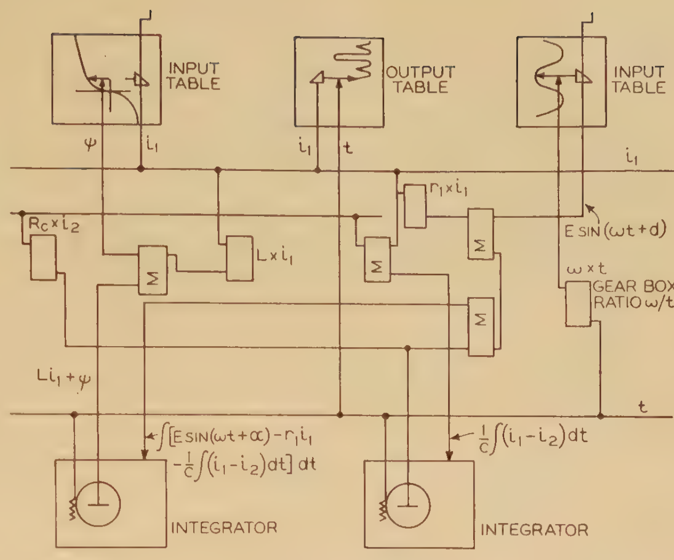


Figure 3. Schematic diagram of differential analyzer connections for solution of circuit equations

tending to reduce the offset and then actually to build up an offset in the negative direction. This process continues, at a rate proportional to the magnitude of the voltage trapped on the capacitor, until saturation is reached in the negative direction. When this occurs a large negative current is drawn, discharging the capacitor. This large negative current may discharge the capacitor partially, completely, or may put on a charge in the reverse direction. It is easily seen that, except for a fortuitous combination of circumstances, the discharge will be either partial or an overshoot. If it is partial the flux will reach a larger negative value at the next cycle, and then the capacitor will receive an opposite charge. This negative charge will, of course, have the effect of reducing the negative offset and then building up a positive offset, so that the cycle of abnormal operation is complete.

Since the rate of decrease of offset is proportional to the voltage on the capacitor, the apparent frequency of occurrence of these large currents (due to saturation being reached) is necessarily dependent on the voltage applied and on the angle at which it is applied. For instance, the larger the initial charge on the capacitor, the sooner it will build the linkages down to the saturable place on the negative side, and give a higher frequency appearance to the exciting current.

In order to demonstrate this property of the circuit, solutions, as given by the analyzer with different values of voltage applied at the zero point of the wave, are shown in figure 4. The periodicity increasing with the applied voltage is clearly seen. If the voltage is increased sufficiently, the circuit can be made to saturate every half cycle and results such as those obtained by Suits[17] are then obtained.

C. Summary of Results Obtained From the Differential Analyzer

It is felt that the major contribution this investigation made was that of explaining and clarifying to a certain degree the physics of the phenomenon. In order to appreciate the "goings on" in the circuit, fundamental circuit concepts must be kept in mind, as vector diagrams, resonance, sustained harmonic solutions, and other linear circuit concepts fail when nonlinear parameters are employed.

The effect of a damping resistor shunting the capacitor was investigated and the results are summarized in figure 7.

In these figures, the region above each curve represents an unstable or abnormally excited circuit condition; that is, if a given circuit has a value of capacitance and shunting resistance that fall in the area above the corresponding curve and the voltage is applied at or near the zero point on the wave, the circuit will draw a sustained large distorted magnetizing current. All points below each curve represent a so-called stable area where the circuit will have its normal low value of magnetizing current. The various curves show the effect of changing the line reactance, the line resistance, and the transformer iron characteristic. The 2 iron characteristics are shown in figure 8. Curve 1 represents the magnetization curve of a modern transformer. Curve 2 was taken arbitrarily to have the current scale of curve 1 multiplied by 3 merely to show the effect of a different magnetizing characteristic or of a larger transformer.

In figure 7 the value of capacitance, to which the left side of each curve is asymtotic, represents the value of capacitive reactance that must be used to prevent the circuit from going into a state of overexcitation without a damping resistor. Unfortunately these values are so low, that they can seldom be useful in correcting a bad voltage condition.

These curves were all determined for normal voltage applied at the zero point of the wave. In certain cases, it may be found that a resistance sufficient to insure normal operation under these conditions will not be low enough if the system is operated at a different voltage. For example, figure 5 illustrates a case in which reducing the voltage caused an abnormal state of excitation. Curve 1 shows normal operation at normal voltage, while curve 2 shows the overexcited condition occurring when 0.75 voltage is applied. Both voltages were applied at the zero point of the wave. This indicates also that in some cases the application of voltage at the zero point of the wave may not be the worst condition since in a sense a shift of angle is partially equivalent to a reduction of voltage, at least as far as the initial charge given to the condenser is concerned.

A circuit having a resistance shunting the saturable inductance, simulating a load being taken off the circuit

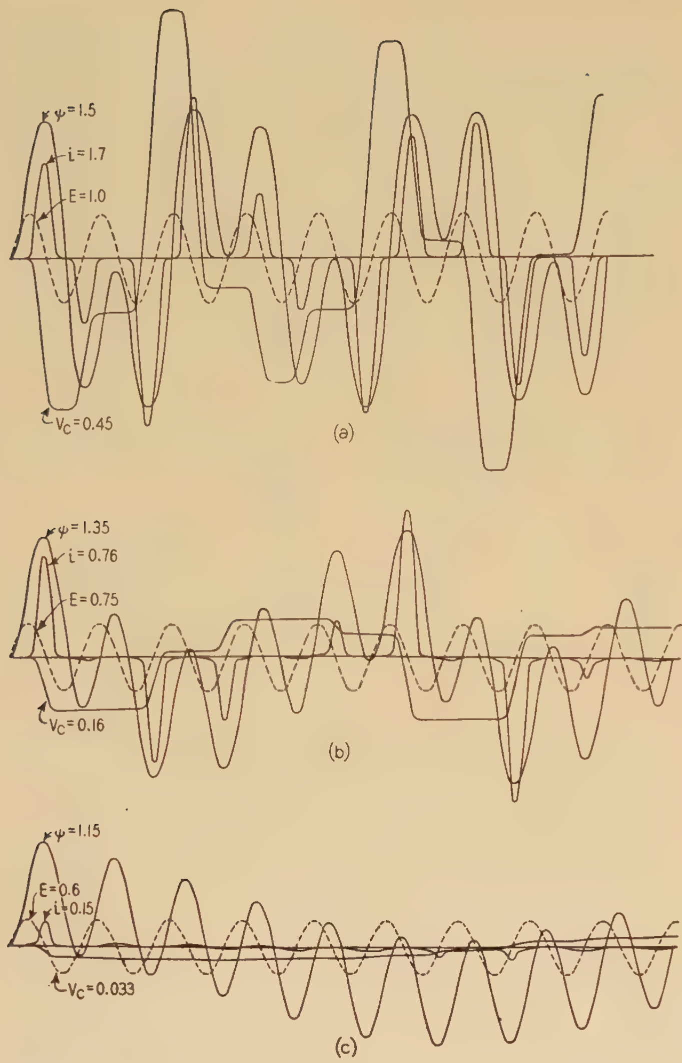


Figure 4. Effect of applied voltage on the apparent periodicity of exciting current

$r_1 = 0.049$	$1/C = 0.214$	(a) $E = 1.0$
$R_c = \infty$	Magnetization curve 1	(b) $E = 0.75$
$L = 0.197$	$\alpha = 0$	(c) $E = 0.6$

between the transformer and the capacitor, was also investigated on the differential analyzer. The critical points obtained with this circuit agreed very well with the points for the same resistance when it was shunting the capacitor, indicating that it made little difference where the resistor was located.

From figure 2 it may be seen that the 2 locations of the resistor are equivalent to 2 locations of the applied voltage, the circuit remaining unchanged. Further, in the canonical equations for a general linear circuit, consisting of any number of meshes, the characteristic determinant is independent of the magnitude or location of the applied voltages. It is therefore evident that the *form* of the transient response, or the building up or dying away of a transient current, is also independent of where the voltage is applied.

This reasoning, showing that in a *linear* circuit, the location of the resistor does not affect the periodicity of the circuit, combined with the differential analyzer results for the nonlinear circuit, indicate that this may well be a general conclusion. It has been known in practice that intervening or secondary loads prevent this overexcitation condition, but the effect had not been previously investigated quantitatively.

D. Conclusions

An unloaded transformer, operating at normal densities, if excited through a series capacitor of reasonable reactance, is susceptible to conditions of large distorted magnetizing currents. These abnormal conditions can be restored to normal by the addition of a suitable shunting resistor to the capacitor, as indicated by figure 7, or by the locating of a certain amount of load on the load side of the capacitor.

The resistor shunting the capacitor, introduces additional losses. However, in general, this loss is less than 10 per cent of the normal line loss and this can usually be justified by the improvement in voltage regulation. Moreover, since the presence of the abnormal condition depends on the initial transient, it may be eliminated by shorting out the capacitor only while the starting switch is being closed, or by having the resistor connected only during the energizing period. The shorting switch or temporary resistor may readily be arranged so as to function automatically whenever the abnormal condition tends to develop.

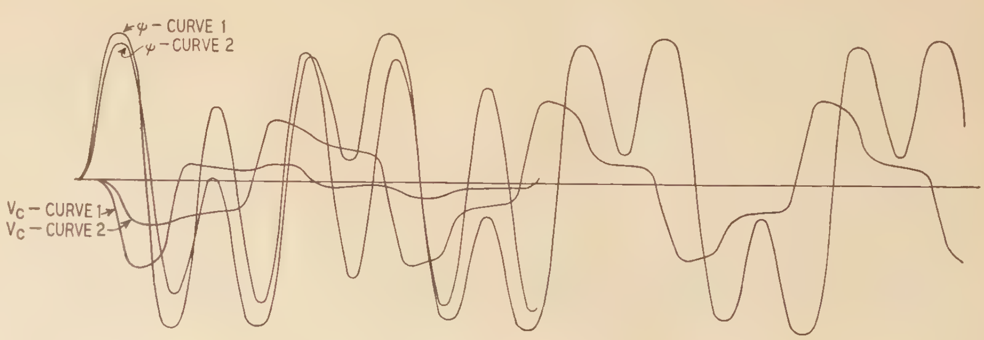
Section II—Hunting of Synchronous Machines

A. General

An electric power system consists in general of a group of interconnected synchronous machines together with impedance and induction motor loads. Any such system is subject at practically every instant of its existence to disturbances caused by changes in load, switching, pulsating loads, pulsating driving torques, changes in excita-

Figure 5. Effect of voltage on excitation

Curve 1 $E = 1.0$. Normal excitation, capacitor voltage decreases
Curve 2 $E = 0.75$. Abnormal excitation, capacitor voltage builds up
$1/C = 0.35$ $L = 0.394$
$R_c = 6.3$ $r_1 = 0.197$
$\alpha = 0$ Magnetization curve 2



tion, etc. These disturbances tend to set up rotor oscillations of the synchronous machines, with consequent voltage and frequency pulsations. Therefore, for satisfactory operation, the system constants must be such as to cause any such oscillations to disappear rapidly if due to a momentary disturbance, or to remain of small amplitude if due to a continuous pulsating force. A momentary disturbance will, in general, produce oscillations of the synchronous machines at all of the principal natural frequencies of the system, while a sustained pulsating force of any frequency will of course produce machine oscillations of the same frequency.

B. Effect of Line Resistance and Series Capacitance

The inherent damping of the system is usually sufficient to prevent severe hunting. However, in certain cases the damping may be either too small to be effective or may actually be negative. That is, the rotor oscillations may be amplified rather than damped out. There are present in all systems 2 conflicting effects. Resistances in the rotor circuits, some types of load, and mechanical friction will produce true damping of rotor oscillations, while resistance in the lines or armature circuits tend to produce amplifying rotor oscillations (or negative damping).

In the case of a single synchronous generator connected to an infinite bus, it has previously been shown[11,12] that the ratio of line resistance to line reactance determines whether or not there is negative damping, and that if all rotor circuits except the field winding are neglected, there is a critical operating angle determined by this ratio above which the machine is unstable. The critical angle is always decreased by the presence of rotor windings, so the method provides a conservative criterion.

If a series capacitor is used in the line the ratio of line resistance to line reactance is increased, since the reactance has been reduced. Consequently the tendency toward negative damping is increased.

C. System of Several Machines

In case of a system consisting of several machines, it is shown in appendix *B* that there is a corresponding relation among the line resistances and reactances which determines the negative damping and that therefore such damping will be affected by the insertion of series line capacitors. However, it cannot be expected now to be a simple resistance-to-reactance ratio; instead the criterion for stable operation is a ratio of certain combinations of line constants. For example, if the case treated in reference 11 is extended to include shunt loads taken off the line, the criterion becomes the ratio of the resistance to the reactance components of the transfer impedance between the synchronous machine and the infinite bus (see appendix *B*, equation 8*b*).

In appendix *B* a system consisting of 2 synchronous generators, an infinite bus, and a shunt load (see figure 9) has been analyzed. This is believed to be sufficiently general to form a basis for the study of almost any particular case which may arise. The critical operating angle of either generator in this general case is shown to be dependent not only on the ratio of combinations of the line constants, but also on the operating angle of the second machine and on its relative amplitude and phase of oscillation. The line constants enter the equation as ratios of the resistance to the reactance components of the several transfer and driving point impedances and so are correlated to the criterion developed by Nickle and Pierce.[11]

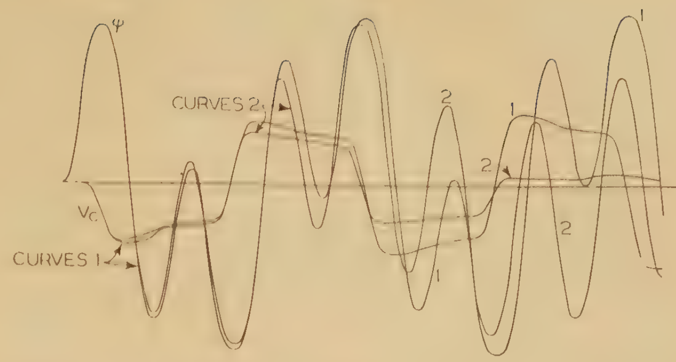


Figure 6. Linkage and capacitor voltage curves with critical values of R_c

Curve 1— $R_c = 6.7$. Abnormal, capacitor voltage builds up
Curve 2— $R_c = 4.2$. Normal, capacitor voltage decreases
$\alpha = 0$ $\quad r_1 = 0.197$ $\quad$ Magnetization curve 1
$L = 0.394$ $\quad 1/C = 0.21$

The equations of appendix *B* may be used to study any particular proposed series capacitor application to determine whether or not it is in the danger zone and, if it is, to determine the optimum location and maximum permissible reactance of the series capacitor consistent with proper line drop compensation. These equations also enable the effectiveness of putting additional series reactance in certain machine circuits to be evaluated.

D. Discussion of Results

As an example of the method of analysis, a problem in which the circuit may be represented as in figure 9 has been worked out. In this case the synchronous generators at 1 and 4 ordinarily supply the load, line 3 merely acting as a tie to the large system at 3. However, occasionally power must be supplied to 4 from 3. Under this condition the voltage regulation at 4 is rather poor and it is desired to correct it by the insertion of a series capacitor between points 3 and 4. As considerable line drop occurs in line 3 the logical place to put the capacitor might seem to be in that line so as to give loads at 2 some benefit. Unfortunately, when this is done the hunting of machine 1 is found to be excessive, while if the capacitor is placed in line 4 hunting is no worse than without the capacitor. The desired result of correcting the bad voltage condition at 4 is accomplished by putting the capacitor in line 4. However in this location the additional advantage of correcting the voltage at the junction is not obtained.

Table I shows the results of calculations of the minimum permissible load angle of machine 1 for stability, under the 3 conditions of no capacitor, capacitor in line 4, and capaci-

tor in line 3, and also for different reactances in branch 4 and with and without shunt load. It is evident from this table that the capacitor in 4 causes a much smaller difference from the original condition than it does when in branch 3.

Although a picture can thus be obtained of the relative tendencies toward hunting of several proposed arrangements, it has not been absolutely determined by calculation that one arrangement will operate satisfactorily and another will not. This is still a matter of judgment fortified by a correlation of field experience with the calculations.

The critical angles recorded in table I are the load angles δ_1–δ_1' where δ_1 is found as described in appendix *C* and δ_1' is the no-load angle of machine 1 referred to the infinite bus 3. The oscillation of machine 4 was neglected (i.e., $k = 0$), since it was assumed that the machine being investigated would have the largest amplitude of oscillation. Also it was found that the necessary load angles were only slightly affected by the operating angle δ_4 of machine 4. It is therefore possible to use the simplified formula (8*b*.1) for nearly every case by simply substituting the value of z_3 ($z_3 = r_3 + jx_3$) paralleled with z_4 for the z_3 of equation (8*b*.2).

A more exact study of a system may be made by taking the amortisseur windings of the machines into account and computing the damping coefficients by the methods of reference 25 for every probable mode of vibration. The

Table I

Condition	Critical Load Angle ($\delta_1 - \delta_1'$) of Machine 1 (Degrees)
No capacitor............ $r_2 = \infty$, $x_4 = 0.2$, $r_4 = 0.05$	1.38
Capacitor in number 4.... $r_2 = \infty$, $x_4 = 0.2$, $r_4 = 0.05$	1.32
Capacitor in number 3.... $r_2 = \infty$, $x_4 = 0.2$, $r_4 = 0.05$	4.14
No capacitor............ $r_2 = 1$, $x_4 = 0.2$, $r_4 = 0.05$	1.48
Capacitor in number 4.... $r_2 = 1$, $x_4 = 0.2$, $r_4 = 0.05$	1.40
Capacitor in number 3.... $r_2 = 1$, $x_4 = 0.2$, $r_4 = 0.05$	3.94
No capacitor............ $r_2 = \infty$, $x_4 = 1.07$, $r_4 = 0.049$	1.72
Capacitor in number 4.... $r_2 = \infty$, $x_4 = 1.07$, $r_4 = 0.049$	1.70
Capacitor in number 3.... $r_2 = \infty$, $x_4 = 1.07$, $r_4 = 0.049$	2.46
No capacitor............ $r_2 = 1$, $x_4 = 1.07$, $r_4 = 0.049$	1.88
Capacitor in number 4.... $r_2 = 1$, $x_4 = 1.07$, $r_4 = 0.049$	1.88
Capacitor in number 3.... $r_2 = 1$, $x_4 = 1.07$, $r_4 = 0.049$	2.67

See figure 9 for circuit.

$r_1 = 0$	$r_3 = 0.023$	$x_q = 0.65$	$x_3 = 0.0516$
$r_2 = \infty$ or 1	$r_4 = 0.05$	$x_2 = 0$	$x_4 = 0.20$ or 1.07

$x_C = 0.105$ = capacitive reactance

Note: x_q and x_4 include both line and machine reactances.

modes of vibration corresponding to the 2 principal natural frequencies of the system of figure 9, or to any impressed forces, can be very simply calculated if the inertia constants of the machine are known. This will not usually be necessary, however, since sufficient information can be obtained from a study of the system neglecting amortisseur windings and a knowledge of the general effects of such windings. (See, for example, reference 19.)

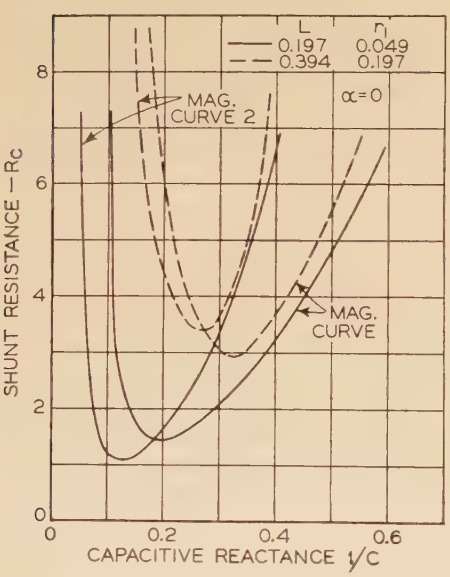
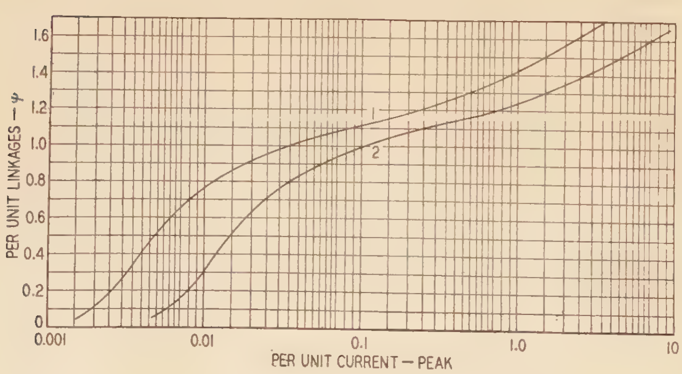


Figure 7. Limits of normal excitation as a function of R_c and 1/C. Area below each curve is normal. Area above each curve is abnormal

Figure 8 (below). Magnetization curves. Curve 2 is curve 1 with current scale multiplied by 3



Section III—Self-Excitation of Induction Motors

A. General

It is well known that an induction machine will operate as a generator and that such operation depends on the supplying of excitation from either a synchronous machine or a capacitor even though in case of the capacitor the operation has not previously been very well understood.

Now consider an induction motor supplied through a line containing a series capacitor. Then in addition to the currents flowing due to normal operation of the motor, under certain conditions the motor may act as an induction generator of current of lower than normal frequency. This low-frequency current is limited only by the impedance of the supply circuit at the low frequency, and may reach relatively large values. These large low-frequency currents manifest themselves not only as current surges and voltage swings but also as strong oscillations of the motor rotor caused by the large pulsating torques produced.

This phenomenon of self-excitation will not always take place and may always be entirely eliminated by sufficient line or shunt resistance, or by judiciously locating the capacitor. It may, moreover, be calculated with reasonable certainty and accuracy by equations given in appendix *C*, if the circuit constants and operating conditions are known.

Figures 10 to 13 show the regions in which self-excitation is likely to occur for the case of a purely induction motor load. Figures 10 and 11 show the effect of series

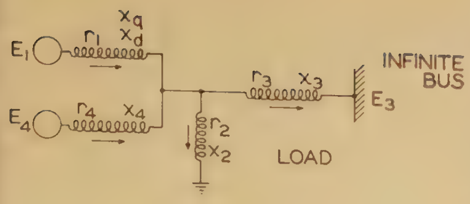


Figure 9. Circuit diagram of 2 synchronous machines connected to infinite bus and impedance load

line resistance in preventing self-excitation, while figures 12 and 13 show how a resistance in shunt with the capacitor can eliminate the phenomenon. For any practical case the reactance of the series capacitor will of course be much less than x', probably about half of x', since x' is the short-circuit reactance of the motor including line reactance and since the capacitor reactance will usually be no greater than line reactance. Therefore figure 14 is given, showing the shunt resistance necessary to prevent self-excitation in the useful range of capacitance, for 2 sets of system constants.

The values of shunt resistance given in the curves will usually be conservative because the effect of series line resistances and machine losses, which themselves tend to damp out self-excitation, has been neglected. Equations are given in appendix *C* which take both shunt and series resistance into account and which should be used to analyze any specific problem. These are based on the analysis presented in reference 20. Figure 15 shows an example of how the value of α necessary for stability decreases with increasing line resistance.

B. Discussion of Results

Figure 10 shows that as long as the capacitive reactance is less than half of the system short-circuit reactance, self-excitation will not occur for a normally loaded group of induction motors. This is because the line resistance is usually great enough to damp out any tendency to self-excite. However, as soon as a certain critical value of short-circuit reactance is exceeded the amount of series resistance required begins to increase rapidly. This critical value of reactance is, of course, a function of the motor characteristics and the impedance of the connected circuit. If the line is relatively short (i.e., if its reactance is less than the motor reactance) it may be compensated more than if it is long, unless a shunt resistor is added to prevent self-excitation.

Figure 11 shows that as the motor speed decreases the region of self-excitation moves down along the x_c ordinate. That is, the tendency to self-excite occurs at a lower value of capacitive reactance at lower motor speeds. Such low speeds occur during starting and during periods of overload. We should thus expect some oscillations as the motor comes up to speed. This is especially true if a starting resistance is used in the rotor, as figures 10 and 12 indicate that an increase of rotor resistance increases the tendency to self-excite. In general it will not be necessary to eliminate these transient oscillations. Actually, in service when the system behaves correctly under normal operating conditions no trouble during starting has been experienced. If, however, the system does not have very much margin at normal load, a sustained overload may produce self-excitation.

C. Calculations and Test Results

In order to check the theory offered for this so-called "self-excitation phenomenon," tests were conducted on a miniature set-up, in order to get good control of the variables. A 3-phase $^3/_4$-horsepower wound-rotor induction motor was connected to a power source through a series capacitor and 0.39 per unit external reactance. The values of series capacitance were varied over the complete range of self-excitation, and the corresponding value of shunting resistance to insure normal operation was determined. These tests results, and corresponding calculated points on the curve are shown plotted in figure 16. The agreement between test and calculated values was very gratifying. It is felt that the equations offered can be used with confidence in predetermining these regions of abnormal operation.

The motor was tested running light, hence the speed was taken as unity to simplify the calculations. The armature resistance of the motor and external circuit was 0.10 per unit. This high circuit resistance is the reason for the curve in figure 16 intersecting the $\alpha = 0$ point at such a high value of x_c. The rotor resistance was likewise very high, hence the motor had a correspondingly small rotor time constant. The small rotor time constant gives the motor a greater tendency to self-excite as shown in figures 10 and 12.

In view of the type of motor tested, that is, one having high resistances, these test results should not be generalized as significant of normal motor performance.

The line of demarkation between normal operation and

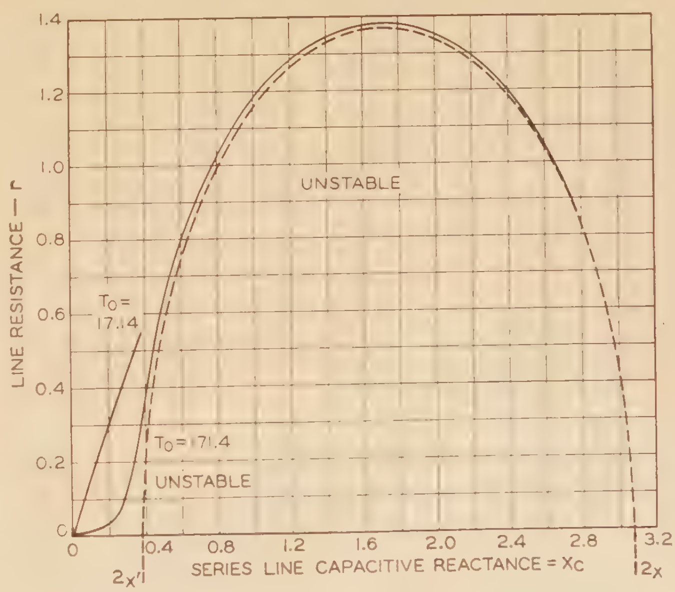


Figure 10. Self-excitation of induction motors with series capacitors

Showing series resistance required for stable operation as a function of the line capacitance and showing effect of varying rotor resistance

$x' = 0.4$ $x = 3.24$ $T_0 = 171.4$ and 17.14 $\omega = 0.975$

self-excitation was very sharp up to $x_c = 0.6$. Calculations and tests both showed this. Beyond $x_c = 0.6$ the calculated curve became more difficult to determine because it seemed to be very broad in the upper regions, that is, it was difficult by ordinary slide rule methods to get a smooth curve, indicating the critical region was not very sharply defined. Tests bore this point out in the upper regions. The test points plotted are the largest values

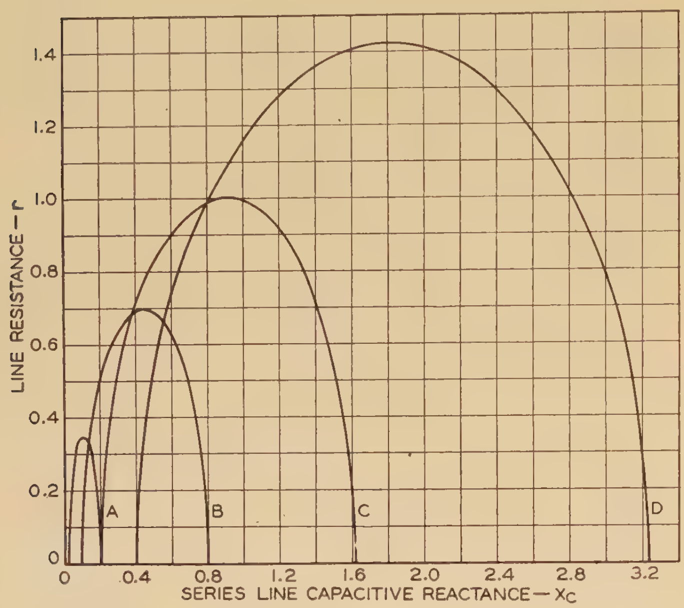


Figure 11. Self-excitation of induction motors with series capacitors

Showing effect of varying motor speed

A—$\omega = 0.25$ B—$\omega = 0.5$ C—$\omega = 0.707$ D—$\omega = 1.0$
$x' = 0.4$ $x = 3.24$ $T_o = 171.4$

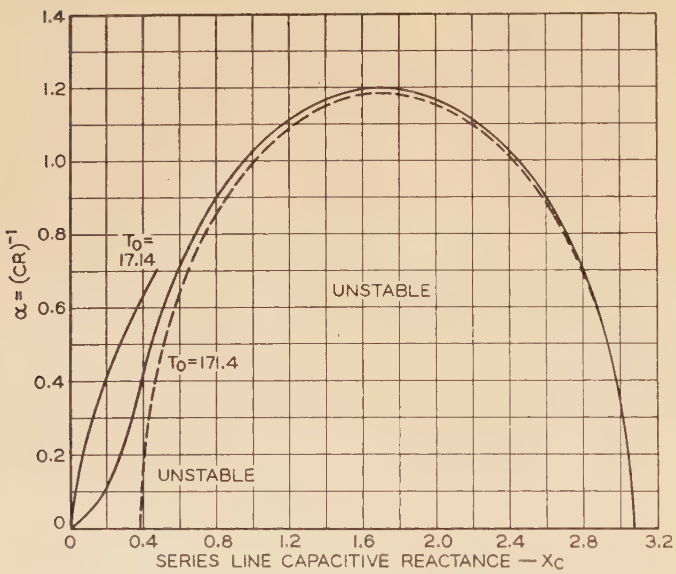


Figure 12. Self-excitation of induction motors with series capacitors

Showing resistance (in shunt with the capacitor) required for stable operation as a function of the line capacitance and showing effect of varying rotor resistance

$x' = 0.4$ $x = 3.24$ $\omega = 0.975$ $r = 0$

of α found for each value of x_c. The current wave was watched through an oscilloscope and self-excitation could be readily recognized by a change in the wave. In the lower regions below $x_c = 0.6$, the phenomenon was more violent and critical. A change of a few per cent in the value of shunting resistance R in this region, would be sufficient to change the circuit from normal to a definite state of self-excitation. The region of self-excitation in the practical and useful range of x_c can be readily recognized by calculation since this range is below $x_c = 0.6$.

Figure 17 is an oscillogram of the current flowing in one phase during the motor starting period, and of the subsequent flow of current when the circuit is in the state of self-excitation. It will be noted that in this case the motor came up to speed in the normal manner, with normal inrush and sustained current. However in several cycles the current built up to several times normal with obvious superposed frequencies, which are identified as the natural currents of the system having positive decrement factors. These currents are ultimately limited in magnitude by saturation and the current builds up until the circuit constants change to a value that will not permit further self-excitation.

D. Self-Excitation of Synchronous Machines

It has been stated above that in circuits containing series capacitors and induction motors, there may be a tendency to self-excite and that in circuits containing series capacitors and synchronous machines there may be a tendency toward hunting. It is evident, however, that the tendency to self-excite (that is, to generate amplifying current oscillations even though the rotor inertia prevents hunting) exists also in synchronous machines. It has been possible to obtain a satisfactory explanation of operating experience with synchronous machines on the basis of hunting alone but it is conceivable that under certain conditions purely electrical self-excitation may be encountered.

While this matter has not been thoroughly studied, the phenomenon is familiar in relation to the determination of the line charging capacity of synchronous generators. S. B. Crary,[21] M. Takahashi,[22] and Y. H. Ku[23] have made a study of this subject and have shown the tendency of line resistance to reduce the self-excitation. By means of the theory given in reference 20, it may further be shown that a resistance in shunt with the capacitor may also be used to eliminate the self-excitation (see appendix D). Figure 18 shows, for the same generator as in figure 1 of reference 21, the effect of shunt resistance.

Since the effect of rotor circuits in addition to the main field has not yet been determined, no definite conclusions can be drawn from this curve, but it is believed worthwhile to point out the existence of such self-excitation and to indicate that it may be corrected exactly as in the case of induction motors. The phenomena of self-excitation and hunting may of course exist simultaneously and are mutually dependent to a limited extent. Their mutual effects have not yet been studied exactly.

The ideal procedure, from a mathematical point of view,

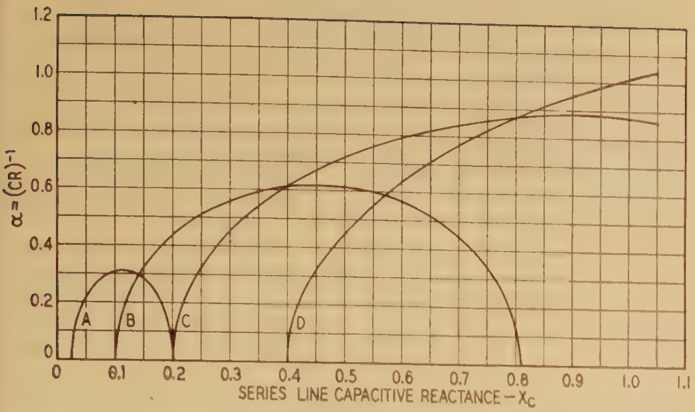


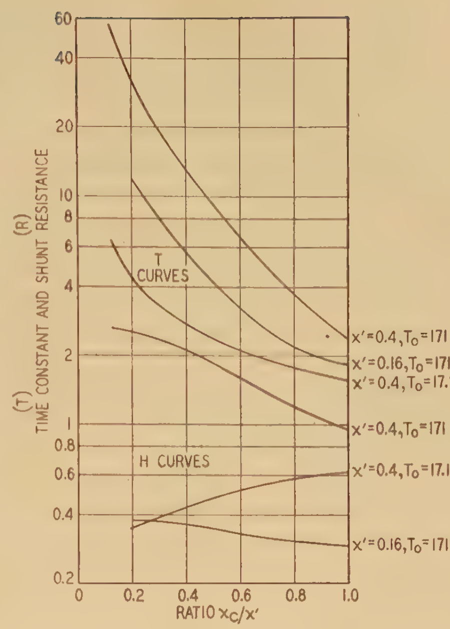
Figure 13. Self-excitation of induction motors with series capacitors

Showing effect of varying motor speed

A—$\omega = 0.25$ B—$\omega = 0.5$ C—$\omega = 0.707$ D—$\omega = 1.0$
$x' = 0.4$ $x = 3.24$ $T_o = 171.4$ $r = 0$

Figure 14. Self-excitation of induction motors with series capacitors

Showing resistance (in shunt with the capacitor) required for stable operation as a function of the line capacitance for various systems
$x = 3$ $r = 0$
$\omega = 0.975$



would be to set up the equations of motion of the circuit including both electrical and mechanical motions, and then to find out whether the system as a whole was stable or unstable. This method brings out very clearly the basic identity of the phenomena of hunting and self-excitation but is, from an engineering point of view, at present impracticable because of the excessive labor involved in the calculations. It is believed that the results obtained by the approximate studies are practically the same as would be found by the unified method.

Nomenclature

Section I

E = applied voltage, maximum value
t = time in radians
α = phase angle of applied voltage
r_1 = line resistance
i_1 = line current
i_2 = current through R_c
R_c = resistance shunting the capacitor
L = line inductance
C = capacitance
ψ = flux linkage
V_c = voltage across capacitor

Sections II and III

E = internal voltage
e_d, e_q = direct and quadrature axis terminal voltages
ψ_d, ψ_q = direct and quadrature axis flux linkages
i_d, i_q = direct and quadrature axis currents
x_d, x_q = direct and quadrature axis synchronous reactances (section II)
r = stator line resistance per phase
δ = angle of voltage E from some reference point
θ = angular displacement of rotor
ω = $p\theta$ = rotor speed
x_c = line series capacitive reactance
T_o = rotor time constant with open-circuited stator
x = direct or quadrature axis synchronous reactance of induction motor including line reactance
x' = direct or quadrature axis transient reactance of induction motor including line reactance
α = x_c/R
R = resistance in shunt with the capacitor
k = $\dfrac{\partial \delta_m}{\partial \delta_n}$
m, n = subscripts given to currents, voltages, impedances, and angles in relating them to certain machines and circuits as used in section II

Appendix A—Derivation of Equations Set Up on the Differential Analyzer

The single-phase circuit analyzed is represented in figure 2. The magnetization curves shown in figure 8 are the 2 iron characteristics that were investigated and discussed in the body of the paper.

The differential equations applying to this circuit are:

$$E \sin(t + \alpha) = r_1 i_1 + L\frac{di_1}{dt} + \frac{1}{C}\int (i_1 - i_2)dt + \frac{d\psi}{dt} \qquad (1a)$$

$$i_2 R_c = \frac{1}{C}\int (i_1 - i_2)dt \qquad (2a)$$

Rearranging and integrating (1a) into a form applicable to the differential analyzer, there is:

$$Li_1 + \psi = \int \left[E \sin(t + \alpha) - r_1 i_1 - \frac{1}{C}\int (i_1 - i_2)dt \right] dt \qquad (3a)$$

The schematic hook-up of the analyzer, giving the solution to equations 2a and 3a is shown in figure 3. The input voltage was actually not cranked in by an operator. Instead an auxiliary set-up was made that gave the solution to the differential equation

$$\frac{d^2x}{dt^2} = -x \qquad (4a)$$

which is a sinusoid, and it was impressed automatically into the hook-up. An operator was needed to crank the current into the system by keeping a pointer representing ψ, the linkage, on the linkage-current characteristic. Values of applied voltage, linkage, capacitor voltage, and total current were plotted by the output tables.

The procedure used to determine the points on the resistance-capacitive reactance curves of figure 7 was as follows. The differential analyzer was started at a point corresponding to application of the voltage at the zero point of the wave and the several dependent variables of the circuit plotted automatically on an output table.

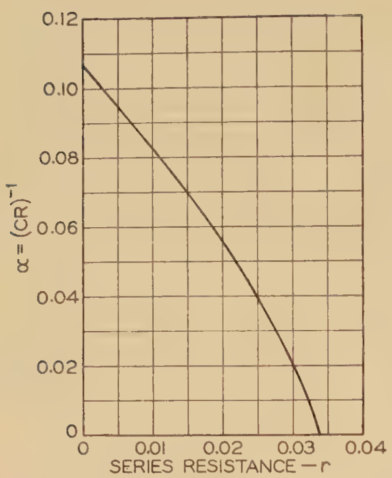
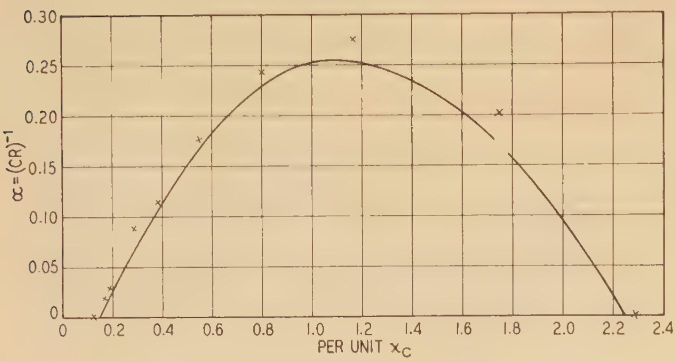


Figure 15. Relation between line resistance and α required to prevent self-excitation

$x = 3.24 \quad x' = 0.4$
$x_c = 0.2$

Figure 16 (below). Self-excitation of induction motors with series capacitors

Comparison of calculated and test results
X—Test points
Curve—Calculated
$x' = 1.03 \quad x = 2.32$
$\omega = 1.0 \quad r = 0.10$



As indicated by the equation above there are several variables which can be used in the interpretation of the analyzer results. The quantities which would ordinarily be measured in test of an actual circuit are the transformer voltage and current. However, it was found by experience that the most significant quantities, as far as the efficient determination of a criterion for proper circuit operation was concerned, were the capacitor voltage and transformer flux. Since, as shown in the oscillograms, the current only appears as an appreciable magnitude at widely separated intervals of time (e.g., figures 1*a* and 4*c*) and, when it does appear, it is likely to bear no obvious relation to its previous value, thus it is very difficult to use current as a continuous indication of the behavior of the circuit. On the other hand, the transformer flux, which bears a direct functional relation to the current as given by the saturation curve, is always of a reasonably large magnitude and of a nearly sinusoidal wave shape. It appears, as shown in figures 4 to 6, as a sinusoidal wave having a slowly varying displacement, and the rate of change and magnitude of this displacement were found to be useful factors in determining as quickly as possible from a given analyzer run, whether or not the circuit would approach its proper steady state.

The capacitor voltage was found to be still more useful in this respect; that is, if one had to judge from the behavior of only one quantity whether the circuit was to approach a normal or abnormal condition, one would choose the capacitor voltage. This voltage determined by its magnitude the rate of change of flux wave displacement, by its rate of discharge the effectiveness of the shunt resistor, by its duration the continuance of the shifting of displacement of the flux wave. In general, it was discovered that if ever the capacitor voltage increased in magnitude from cycle to cycle (it will be understood here that by "cycle" is meant the apparent cycle of the low frequency current pulsations and not that of the applied voltage), for example, if it ever went higher the second time than it did the first, the system behavior was abnormal. On the other hand, if it continually decreased in magnitude from cycle to cycle the circuit operation was sure to be normal. This is illustrated by figure 6 which shows curves of capacitor voltage taken at 2 different values of shunt resistance, one just sufficient to produce normal operation, the other slightly higher.

Appendix B—Criteria for Negative Damping of Synchronous Generators Neglecting Amortisseur Winding

Consider the circuit of figure 9 with 2 generators connected to an infinite bus with a shunt load at the branch point and with resistances and reactances as indicated.

The effects of salient poles will be considered only in machine number 1, the stability of which is being investigated, while machine number 4 is considered to be round rotor. Moreover, the reactance x_4 will usually be taken as the transient reactance or some modified value depending on the frequency of the oscillation being studied.

The steady-state equations for this circuit are:

$$\begin{aligned}
-i_{q1} + i_{q2} + i_{q3} - i_{q4} &= 0\\
x_d i_{d1} + x_2 i_{d2} + r_1 i_{q1} + r_2 i_{q2} &= E_1\\
x_2 i_{d2} - x_3 i_{d3} + r_2 i_{q2} - r_3 i_{q3} &= E_3 \cos \delta_1\\
-i_{d1} + i_{d2} + i_{d3} - i_{d4} &= 0\\
-r_1 i_{d1} - r_2 i_{d2} + x_q i_{q1} + x_2 i_{q2} &= 0\\
r_2 i_{d2} - r_3 i_{d3} - x_2 i_{q2} + x_3 i_{q3} &= E_3 \sin \delta_1\\
x_2 i_{d2} + x_4 i_{d4} + r_2 i_{q2} + r_4 i_{q4} &= E_4 \cos(\delta_1 - \delta_4)\\
r_2 i_{d2} + r_4 i_{d4} - x_2 i_{q2} - x_4 i_{q4} &= E_4 \sin(\delta_1 - \delta_4)
\end{aligned} \tag{1b}$$

If the effect of the amortisseur windings is neglected it has been shown[12] that the load angle below which negative damping of generator number 1 may occur is accurately given by the condition (when the frequency of the mechanical oscillation is small compared to normal-voltage frequency),

$$\frac{d}{d\delta_1} i_{d1} = 0 \tag{2b}$$

Solving equations 1*b* for i_{d1}, we find

$$\Delta i_{d1} = \begin{vmatrix}
0 & 0 & 0 & 0 & -1 & 1 & 1 & -1\\
E_1 & x_2 & 0 & 0 & r_1 & r_2 & 0 & 0\\
E_3 \cos \delta_1 & x_2 & -x_3 & 0 & 0 & r_2 & -r_3 & 0\\
0 & 1 & 1 & -1 & 0 & 0 & 0 & 0\\
0 & -r_2 & 0 & 0 & x_q & x_2 & 0 & 0\\
E_3 \sin \delta_1 & r_2 & -r_3 & 0 & 0 & -x_2 & x_3 & 0\\
E_4 \cos(\delta_1 - \delta_4) & x_2 & 0 & x_4 & 0 & r_2 & 0 & r_4\\
E_4 \sin(\delta_1 - \delta_4) & r_2 & 0 & r_4 & 0 & -x_2 & 0 & -x_4
\end{vmatrix} \tag{3b}$$

where Δ is the determinant of the coefficients of the currents in equations 1*b*.

Differentiating with respect to δ_1, there is

$$\Delta \frac{d}{d\delta_1} i_{d1} = \begin{vmatrix}
0 & 0 & 0 & 0 & -1 & 1 & 1 & -1\\
0 & x_2 & 0 & 0 & r_1 & r_2 & 0 & 0\\
-E_3 \sin \delta_1 & x_2 & -x_3 & 0 & 0 & r_2 & -r_3 & 0\\
0 & 1 & 1 & -1 & 0 & 0 & 0 & 0\\
0 & -r_2 & 0 & 0 & x_q & x_2 & 0 & 0\\
E_3 \cos \delta_1 & r_2 & -r_3 & 0 & 0 & -x_2 & x_3 & 0\\
-E_4(1-k)\sin(\delta_1 - \delta_4) & x_2 & 0 & x_4 & 0 & r_2 & 0 & r_4\\
E_4(1-k)\cos(\delta_1 - \delta_4) & r_2 & 0 & r_4 & 0 & -x_2 & 0 & -x_4
\end{vmatrix} \tag{4b}$$

where $k = \dfrac{\partial \delta_4}{\partial \delta_1}$, i.e., k is the ratio of the motion of machine number 4 to that of machine number 1. For sinusoidal oscillations k may be taken as the ratio of the amplitude of the machine oscillations.

Equation 4*b*, together with equation 2*b*, may be written

$$0 = \Delta \frac{d}{d\delta_1} i_{d1} = -E_3(M_{31} \sin \delta_1 + M_{61} \cos \delta_1) - E_4[M_{71} \sin(\delta_1 - \delta_4) + M_{81} \cos(\delta_1 - \delta_4)](1 - k) \tag{5b.1}$$

or

$$\tan\delta_1 = -\left[\frac{M_{61} + (1-k)\dfrac{E_4}{E_3}(M_{81}\cos\delta_4 - M_{71}\sin\delta_4)}{M_{31} + (1-k)\dfrac{E_4}{E_3}(M_{71}\cos\delta_4 + M_{81}\sin\delta_4)}\right] \qquad (5b.2)$$

The relation $\dfrac{d}{d\delta_1} i_{d1} = 0$ thus leads to a transcendental equation which may be solved numerically for δ_1 as a function of δ_4.

In equations 5*b*, there is

$$M_{31} = \begin{vmatrix} x_2 & 0 & r_1 & -r_2 & 0 \\ -r_2 & 0 & x_q & -x_2 & 0 \\ r_2 + r_3 & -r_3 & x_3 & x_2 + x_3 & x_3 \\ x_2 & x_4 & 0 & -r_2 & r_4 \\ r_2 & r_4 & 0 & x_2 & -x_4 \end{vmatrix} \qquad (6b.1)$$

$$M_{61} = \begin{vmatrix} x_2 & 0 & r_1 & r_2 & 0 \\ x_2 + x_3 & -x_3 & -r_3 & r_2 + r_3 & -r_3 \\ -r_2 & 0 & x_q & x_2 & 0 \\ x_2 & x_4 & 0 & r_2 & r_4 \\ r_2 & r_4 & 0 & -x_2 & -x_4 \end{vmatrix} \qquad (6b.2)$$

$$M_{71} = \begin{vmatrix} x_2 & 0 & r_1 & -r_2 & 0 \\ x_2 & x_3 & 0 & -r_2 & -r_3 \\ -r_2 & 0 & x_q & -x_2 & 0 \\ r_2 & r_3 & 0 & x_2 & x_3 \\ r_2 + r_4 & -r_4 & x_4 & x_2 + x_4 & -x_4 \end{vmatrix} \qquad (6b.3)$$

$$M_{81} = \begin{vmatrix} x_2 & 0 & r_1 & r_2 & 0 \\ x_2 & -x_3 & 0 & r_2 & -r_3 \\ -r_2 & 0 & x_q & x_2 & 0 \\ r_2 & -r_3 & 0 & -x_2 & x_3 \\ x_2 + x_4 & x_4 & -r_4 & r_2 + r_4 & r_4 \end{vmatrix} \qquad (6b.4)$$

In the special case for which the motions of the 2 machines are the same ($k = 1$), equations 5*b* reduce to

$$\tan\delta_1 = -\frac{M_{61}}{M_{31}} \qquad (7b)$$

but this is not likely to be a useful case. If $k = 0$, there is no simplification.

If machine number 4 is eliminated by letting x_4 and/or r_4 be infinite, M_{71}, M_{81} become negligible compared to M_{31}, M_{61}, and equations 5*b* reduce to:

$$\tan\delta_1 = \frac{\begin{vmatrix} x_2 & -r_1 & r_2 \\ x_2 + x_3 & r_3 & r_2 + r_3 \\ -r_2 & -x_q & x_2 \end{vmatrix}}{\begin{vmatrix} x_2 & r_1 & -r_2 \\ -r_2 & x_q & -x_2 \\ r_2 + r_3 & x_3 & x_2 + x_3 \end{vmatrix}} \qquad (8b.1)$$

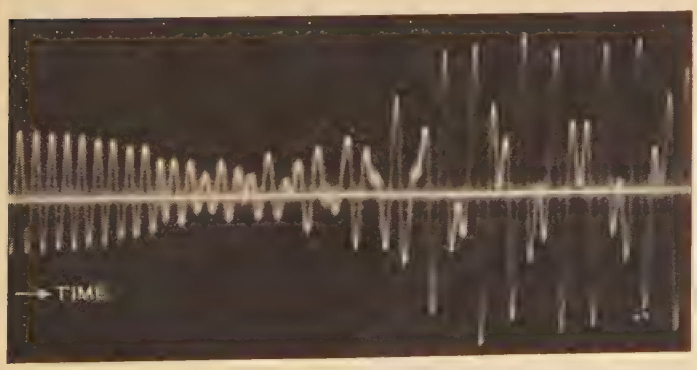


Figure 17. Starting and self-excited current of induction motor with series capacitance in primary circuit

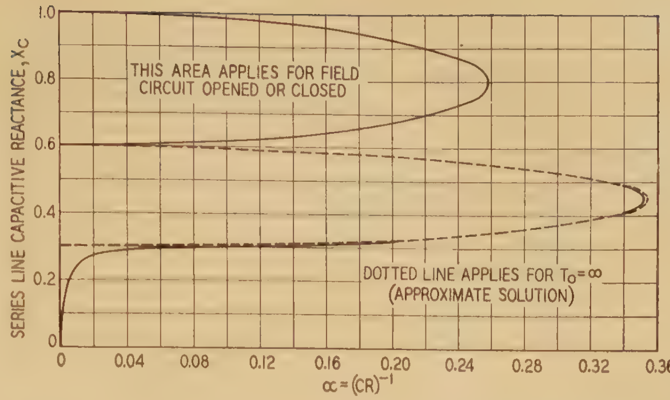


Figure 18. Regions of self-excitation of synchronous machine with armature capacitance as affected by shunt resistance R

$x_d = 1.0 \quad x_q = 0.6 \quad x_d' = 0.30 \quad T_o = 1{,}000 \quad r = 0$

or

$$\tan\delta_1 = \frac{Z_2^2(r_1 + r_3) + x_q(r_3x_2 - x_3r_2) + r_1(x_2x_3 + r_2r_3)}{Z_2^2(x_q + x_3) + x_q(x_2x_3 + r_2r_3) + r_1(x_3r_2 - x_2r_3)} \qquad (8b.2)$$

where

$$Z_2^2 = r_2^2 + x_2^2$$

The right-hand side of equation 8*b*.2 is recognized as the ratio of the real to the imaginary part of the transfer impedance from machine number 1 to the infinite bus if x_q is used for the machine reactance. Further, if the shunt load is removed ($Z_2 = \infty$) it checks the criterion of reference 11.

If the shunt load is removed but machine number 4 is kept, the form of equation 5*b* is unchanged but equations 6*b* are reduced to:

$$-M_{31} = \begin{vmatrix} -r_3 & x_q + x_3 & x_3 \\ x_4 & -r_1 & r_4 \\ r_4 & x_q & -x_4 \end{vmatrix} \qquad (9b.1)$$

$$-M_{61} = \begin{vmatrix} x_3 & r_1 + r_3 & r_3 \\ -x_4 & r_1 & -r_4 \\ r_4 & x_q & -x_4 \end{vmatrix} \qquad (9b.2)$$

$$-M_{71} = \begin{vmatrix} -x_3 & r_1 & r_3 \\ r_3 & x_q & x_3 \\ -r_4 & x_q + x_4 & -x_4 \end{vmatrix} \qquad (9b.3)$$

$$-M_{81} = \begin{vmatrix} x_3 & r_1 & r_3 \\ -r_3 & x_q & x_3 \\ -x_4 & r_1 + r_4 & -r_4 \end{vmatrix} \qquad (9b.4)$$

If in equations 5*b* $E_4 = 0$, or if x_4 and/or $r_4 = \infty$, there is,

$$\delta_1 = -\tan^{-1}\frac{M_{61}}{M_{31}} \qquad (10b)$$

which is equation 7*b* if $E_4 = 0$, and is equation 8*b* if x_4 or $r_4 = \infty$. If $E_4 = 0$ but x_4 and r_4 are finite, equation 10*b* may of course be put in the form 8*b* by paralleling Z_2 and Z_4, i.e., in equation 8*b* replace r_2 and x_2 by the corresponding real and imaginary parts of the parallel values of Z_2 and Z_4. This reasoning shows that since $\tan\delta$ in (8*b*.2) equals the ratio of the real and imaginary components of the transfer impedance from machine number 1 to the infinite bus (number 3) therefore $-M_{61}/M_{31}$, where M_{61} and M_{31} are given by (6*b*.1) and (6*b*.2), must also be the ratio of the real and imaginary parts of the transfer impedance of machine number 1 to the infinite bus with Z_4 finite. In fact, directly from equation 3*b* it may be seen that since:

$$\Delta i_{d1} = -M_{21}E_1 + M_{31}E_3\cos\delta_1 - M_{61}E_3\sin\delta_1 + M_{71}E_4\cos(\delta_1 - \delta_4) - M_{81}E_4\sin(\delta_1 - \delta_4) \qquad (11b)$$

Then:

$-M_{21}/\Delta$ is the imaginary part of the driving point admittance at machine number 1

M_{31}/Δ is the imaginary part of the transfer admittance from 1 to 3

M_{61}/Δ is the corresponding real part

M_{71}/Δ is the imaginary part of the transfer admittance from 1 to 4

M_{81}/Δ is the corresponding real part

It follows that since

$$\left(\frac{\text{real}}{\text{imaginary}}\right)_{\text{admittance}} = -\left(\frac{\text{real}}{\text{imaginary}}\right)_{\text{impedance}} \tag{12b}$$

we have

$$-\frac{M_{61}}{M_{31}} = \left(\frac{\text{real}}{\text{imaginary}}\right)_{\text{impedance 1–3}} \tag{13b}$$

and

$$-\frac{M_{81}}{M_{71}} = \left(\frac{\text{real}}{\text{imaginary}}\right)_{\text{impedance 1–4}} \tag{14b}$$

All of these transfer impedances and admittances are computed for *a direct-axis current* in machine number 1. Also, since it is only the relative magnitude of the components of impedance which enter into the final criteria, the impedances calculated entirely by means of x_q can be used. That is, even though x_d occurs in Δ and affects the true values of the impedances, Δ does not appear in the results.

The method of extension to more than 2 machines is evident from equations 2*b*, 3*b*, and 4*b*.

Composite Loads

If the shunt load of figure 9 is a composite load[18] of any kind all the criteria given here may be used unchanged if r_2, x_2 are defined by the relation:

$$\frac{de_2}{di_2} = r_2 + jx_2 \tag{15b}$$

at the load voltage e_2.

Appendix C—Self-Excitation of Induction Motors

The object of this appendix is to present criteria to determine the limits of stable operation of induction motors with series line capacitors. Under certain conditions of load it is found in practice that there will exist undamped current pulsations of apparently low frequency and large magnitude. These pulsations are here considered to be caused by undamped or negatively damped (amplifying) free electrical oscillations. Thus, to determine whether a given (electrical) system is stable or unstable the natural currents are examined. The time variation of these natural currents is specified by the roots of the characteristic determinant of the system. If the real part of any one or more of these roots is positive the system is unstable since then the corresponding component of the transient current is amplifying rather than decaying and will tend to increase indefinitely until limited by changes in the circuit caused by saturation, slowing down or oscillating of the motor rotor, etc. Thus, it is not necessary actually to solve for the roots but only to find the signs of their real parts. To find the actual frequency of the unstable oscillation it is necessary to solve the equation, which is of the sixth degree (or of the third degree if expressed with complex coefficients) and has in general 3 conjugate pair of complex roots or 3 natural frequencies.

Analysis

For an induction or synchronous machine with capacitance and resistance in shunt connected to the terminals, there are the equations (see reference 20):

$$\begin{aligned}(p+\alpha)[e_d - p\psi_d + ri_d + \omega\psi_q] + x_c i_d &= \omega[e_q - p\psi_q + ri_q - \omega\psi_d]\\ (p+\alpha)[e_q - p\psi_q + ri_q - \omega\psi_d] + x_c i_q &= -\omega[e_d - p\psi_d + ri_d + \omega\psi_q]\end{aligned} \tag{1c}$$

where, for an induction motor with completely symmetric rotor and stator,

$$\begin{aligned}\psi_d &= -x(p)i_d\\ \psi_q &= -x(p)i_q\end{aligned} \tag{2c}$$

and

$$x(p) = \frac{x'T_o p + x}{T_o p + 1} \tag{3c}$$

Substituting (2*c*) in (1*c*) and rearranging; there is:

$$\begin{aligned}&\{(p+\alpha)[px(p)+r] + x_c - \omega^2 x(p)\}i_d - \omega\{(p+\alpha)x(p) + px(p) + \\ &\quad r\}i_q = -(p+\alpha)e_d + \omega e_q\\ &\omega\{(p+\alpha)x(p) + px(p) + r\}\, i_d + \{(p+\alpha)[px(p)+r] + x_c - \\ &\quad \omega^2 x(p)\}i_q = -\omega e_d - (p+\alpha)e_q\end{aligned} \tag{4c}$$

and for constant rotor speed the characteristic determinant (the denominator of the expression for current as a function of voltage),

$$\begin{aligned}\Delta = &\{(p+\alpha)[px(p)+r] + x_c - \omega^2 x(p)\}^2 + \omega^2\{(p+\alpha)x(p) + \\ &px(p) + r\}^2\end{aligned} \tag{5c}$$

Substituting (3*c*) in (5*c*) and rearranging in descending powers of p, there is:

$$\begin{aligned}(T_o p + 1)^2\Delta = \Delta' = \; &p^6(x'^2 T_o^2)\\ &+ p^5[(2x'T_o)(x + \alpha x'T_o + rT_o)]\\ &+ p^4[(x + \alpha x'T_o + rT_o)^2 + (2x'T_o)\times\\ &\qquad (\alpha x + \omega^2 x'T_o + r + \alpha r T_o + x_c T_o)]\\ &+ p^3[2x'T_o(x_c + \omega^2 x) + 2(x + \alpha x'\,T_o + rT_o)\times\\ &\qquad (ax + \omega^2 x'T_o + r + \alpha r T_o + x_c T_o)]\\ &+ p^2[(ax - \omega^2 x'T_o + r + \alpha r T_o + x_c T_o)^2 +\\ &\qquad 2(x + \alpha x'T_o + rT_o)(x_c - \omega^2 x) +\\ &\qquad (\alpha x'T_o + 2x + rT_o)^2\omega^2 + 4\omega^2 x'T_o(\alpha x + r)]\\ &+ p[2(\alpha x - \omega^2 x'T_o + r + \alpha r T_o + x_c T_o)\times\\ &\qquad (x_c - \omega^2 x) + 2\omega^2(\alpha x'T_o + 2x + rT_o)\times\\ &\qquad (\alpha x + r)] + (x_c - \omega^2 x)^2 + (\alpha x + r)^2\omega^2\end{aligned} \tag{6c}$$

Equation 5*c* is of the form ($\Delta' = a^2 + b^2$) and so may be factored as [$\Delta' = (a + jb)(a - jb)$] thus at once reducing the order of the equations to be solved by half. However, this is accomplished at the price of introducing complex coefficients. The real parts of the roots of the 2 factors are identical in pairs; the imaginary parts equal and opposite. Thus only one factor need be considered, but it is found that all methods for determining the character of the roots or solving the equation require about the same amount of work as doubling the order and in effect obtaining equation 6*c*.

In complex form the equation may be written as:

$$\begin{aligned}a + jb = \; &x'T_o p^3 + [(x + \alpha x'T_o + rT_o) + j\omega 2x'T_o]p^2 +\\ &[(x_c T_o - \omega^2 x'T_o + \alpha x + r + \alpha r T_o) + j\omega(2x + \alpha x'T_o +\\ &rT_o)]p + [(x_c - \omega^2 x) + j\omega(\alpha x + r)]\end{aligned} \tag{7c}$$

with a similar conjugate expression for $(a - jb)$.

It will be observed that equations 6*c* and 7*c* are almost symmetrical in r and α except that α has sometimes the coefficient x' and sometimes x, which destroys the symmetry. It is therefore expected that all the conclusions and curves obtained will be very similar if the effect of shunt and series resistances are investigated separately, using α as the variable in case of the shunt resistance. Here α may be thought of as the reciprocal of the time constant of the *RC* circuit considered by itself. It is the negative of the coefficient of time in the exponential solution of the *RC* circuit equations.

Approximate Criterion for Instability

It will be found that a very simple and sufficient condition for instability is that the coefficient of p in equation 6*c* be negative. That is, if this coefficient is negative the system is surely unstable,

but if it is positive the system is not necessarily stable. Putting the coefficient equal to zero there is:

$$x_c = \frac{1}{2}\left[(x+x')\omega^2 - \alpha r - \frac{(\alpha x + r)}{T_o}\right] \pm \left\{\frac{(x-x')^2\omega^4}{4} - \frac{\omega^2}{2}(x+3x')\alpha r + \frac{1}{4}\left[\alpha r + \frac{(\alpha x + r)}{T_o}\right]^2 - \omega^2(xx'\alpha^2 + r^2) - \frac{\omega^2}{2}(3x+x')\frac{(\alpha x + r)}{T_o}\right\}^{1/2} \quad (8c)$$

The 2 values of x_c obtained from (8c) for a given system determine the limits of a region which is theoretically surely unstable.

If a set of circuit constants is selected, leaving r and x_c free, then r is varied and x_c computed, a region is outlined as in figure 10 (dashed curve). This figure shows r as a function of x_c if there is no shunt resistor ($\alpha = 0$). If the effect of shunt resistance alone is determined, letting $r = 0$, the dashed curve of figure 12 is obtained.

Equation 8c outlines the unstable region very close to the true boundary over most of the range of instability. However it indicates that instability lies wholly in the range,

$$\omega^2 x' < x_c < \omega^2 x \quad (9c)$$

so that if $x_c < \omega^2 x'$ the system is stable when in fact there is required a certain finite series or shunt resistance to assure stability. Equation 8c is therefore not a good criterion when x_c is small as in the case of series capacitors for line reactance compensation except when the motor is running at low speeds.

Exact Criterion

To find the true boundary in the region $x_c < \omega^2 x'$ the criterion of Routh[24] is used. This is carried out numerically by assigning values to all of the system constants and testing equations 6c or 7c for stability with various values of line or shunt resistance. The boundaries found in this manner are shown in figures 10 and 12 (solid lines). These figures are calculated for a motor of 0.16 per unit transient reactance and an external reactance of 0.24. In figures 10 and 12 there are also plotted boundaries corresponding to operation at the same speed but with some external rotor resistance, the total rotor resistance being 10 times the rotor winding resistance.* The effects of series and shunt resistors have been determined separately in order to show as simply as possible the orders of magnitude of the various quantities involved. However, since there is always some line resistance present, the value of α required need not be as large as that given by the curves of figure 12. Figure 15 shows an example of how the α necessary for stability can be decreased with increasing line resistance, and has been computed from equation 6c by Routh's[24] method.

Effect of Rotor Speed

Equations 6c or 7c may be used to determine exactly the regions of unstable operation at any rotor speed. However, the effect of speed may be more clearly and easily seen from the approximate expression (8c). Since the rotor open-circuit time constant is usually rather large, equation 8c may be further simplified by neglecting terms containing T_o, whence

$$\frac{x_c}{\omega^2} = \frac{1}{2}\left[x + x' - \left(\frac{\alpha}{\omega}\right)\left(\frac{r}{\omega}\right)\right] \pm \sqrt{\frac{(x-x')^2}{4} - \left[xx'\left(\frac{\alpha}{\omega}\right)^2 + \left(\frac{r}{\omega}\right)^2\right] - \frac{(x+3x')}{2}\left(\frac{\alpha}{\omega}\right)\left(\frac{r}{\omega}\right) + \frac{1}{4}\left(\frac{\alpha}{\omega}\right)^2\left(\frac{r}{\omega}\right)^2} \quad (10c)$$

Equation 10c shows that as the speed ω is varied the scales of the r versus x_c or α versus x_c diagram are simply changed so that

x_c is proportional to ω^2 (11c)
r and α are proportional to ω

* If rotor resistance is zero ($T_o = \infty$) there is no instability. Also if $T_o = 0$ or $\omega = 0$ there is obviously no instability.

Since at low speeds the capacitive reactance at which the maximum series resistance or shunt conductance is required is shifted toward the actual capacitive reactance likely to be used in the circuit, equation 10c or 8c then becomes a useful criterion. Having the boundary curve of instability at any one speed, those at any other speed may then be quickly estimated by the relations 11c. Figures 11 and 13 show the effect of varying the rotor speed as determined by equation 10c. Figure 11 shows the effect on the value of series resistance requirod if there is no shunt resistance, while figure 13 shows a similar curve of α versus x_c if $r = 0$.

Equation 10c also provides a means of determining quickly an approximate expression for the value of α required to eliminate instability completely at any speed. This expression is found by equating the radical in equation 10c to zero, which locates a point very close to the maximum of the α versus x_c or r versus x_c boundary curve. Then

$$\left(\frac{\alpha}{\omega}\right)_{\max} = -\frac{(x+3x')r'}{4xx' - r'^2} + \frac{1}{4xx' - r'^2} \times \sqrt{(x+3x')^2 r'^2 + (4xx' - r'^2)[(x-x')^2 - 4r'^2]} \quad (12c)$$

where $r' = r/\omega$.

If $r = 0$, there is

$$\left(\frac{\alpha}{\omega}\right)_{\max} = \frac{(x - x')}{2\sqrt{xx'}} \quad (13c.1)$$

which occurs at

$$\frac{x_c}{\omega^2} = \frac{x + x'}{2} \quad (13c.2)$$

Similarly if $\alpha = 0$, there is

$$\left(\frac{r}{\omega}\right)_{\max} = \frac{(x - x')}{2} \quad (13c.3)$$

which occurs at the same x_c as in equation 13c.2. These last relations determine equations,

$$r^2 = \frac{(x-x')^2 x_c}{2(x + x')} \text{ for } \alpha = 0 \quad (14c.1)$$

and

$$xx'\alpha^2 = \frac{(x-x')^2 x_c}{2(x + x')} \text{ for } r = 0 \quad (14c.2)$$

which are the equations of the loci of the maxima of the r versus x_c and α versus x_c curves as the speed ω is varied. Then, if the capacitive reactance x_c in a given circuit is known equations 14c determine the value of r or α needed to eliminate self-excitation at all speeds. However, as mentioned in the body of the paper, it will not in general be necessary to do this.

Frequency and Time Constant of the Amplifying Oscillation

The frequencies and time constant of all these components of the transient currents may of course be found directly by solving equations 6c or 7c. However, it has been found that within the normal range of circuit constants only one of these currents is amplifying and so likely to be observed as a large current pulsation. Moreover, this current is that corresponding usually to a small root of 7c, over most of the range of x_c. It should therefore be possible to find the root approximately by neglecting higher powers of p in equation 7c whence the solution is

$$p_1 = \frac{(x_c - \omega^2 x) + j\omega(\alpha x + r)}{[(x_c - \omega^2 x' + \alpha r)T_o + \alpha x + r] + j\omega[(\alpha x' + r)T_o + 2x]} \quad (15c)$$

A further obvious simplification is obtained by neglecting the terms in the denominator which do not contain T_o. If $p_1 = p_r + jq$ then p_r is the decrement factor and $(\omega + q)$ the frequency of the possibly amplifying oscillation. The frequency is $\omega + q$ rather than

q since the solution is for i_d, i_q. The phase currents are obtained by Park's[25] equations

$$i_a = i_d \cos\theta - i_q \sin\theta, \text{ etc.}$$

and it may be shown that the component of phase current of frequency $\omega - q$ vanishes identically.

If the real part p_r of p_i is equated to zero (corresponding to the point at which the oscillation is just neutral) equation $8c$ is arrived at by a different route.

The approximate equation $15c$ holds only for $x_c > \omega^2 x'$ and so in the useful range of capacitance at normal motor speeds, equation $7c$ must be solved directly. It is still possible to avoid the solution of a cubic equation if it is desired to find the frequency only at points on the boundaries between the stable and unstable regions, since at such points the root is obviously pure imaginary and if $p = jq$, equation $7c$ may be split up as

$$a + jb = -[(x + \alpha x'T_o + rT_o)q^2 + \omega(2x + \alpha x'T_o + rT_o)q - (x_c - \omega^2 x)] - j[x'T_o q^3 + \omega 2x'T_o q^2 - (x_c T_o - \omega^2 x'T_o + \alpha x + r + \alpha r T_o)q - \omega(\alpha x + r)] \tag{16c}$$

and the real and imaginary components of $(16c)$ equated separately to zero. Sets of system constants on the boundary may then be first found by Routh's[24] method and q then obtained by solving the quadratic equation $a = 0$ in equation $16c$. Of the 2 real roots thus found only one will in general satisfy the cubic equation $b = 0$ of $(16c)$ and this will of course be the proper frequency. For example, taking circuit constants corresponding to the points $x_c = 0.2$, $r = 0.035$ in figure 10, the frequency is found to be very nearly 0.7 times normal (rotor speed). At values of $x_c > x'$ the frequency is always very close to, and slightly less than that corresponding to the rotor speed.

M. Takahashi[22] has an approximate solution of equation $7c$ for the case of no shunt resistance and has determined regions of self-excitation for this case. His results are in general agreement with those given here.

Appendix D—Self-Excitation of Synchronous Machines

From equations 15 of reference 20, the equations of a synchronous machine operating at synchronous speed, with only one rotor winding, with series capacitance and resistance in the armature circuit, and with additional resistors shunting the capacitors, are:

$$\begin{aligned}(p + \alpha)(e_d - p\psi_d + ri_d + \psi_q) + x_c i_d &= e_q - p\psi_q + ri_q - \psi_d \\ (p + \alpha)(e_q - p\psi_q + ri_q - \psi_d) + x_c i_q &= -e_d + p\psi_d - ri_d - \psi_q\end{aligned} \tag{1d}$$

where

$$\psi_d = -x_d(p) i_d = -\frac{x_d' T_o p + x_d}{T_o p + 1} i_d \tag{2d}$$

$$\psi_q = -x_q(p) i_q = -x_q i_q \tag{3d}$$

If $(1d)$ are solved for the currents i_d, i_q in terms of the applied voltages e_d, e_q, it is found that the operational common denominator of the 2 formulas for current is:

$$\begin{aligned}\Delta' = {} & p^5 x_q x_d' T_o \\ & + p^4[x_q x_d + rT_o(x_q + x_d') + 2\alpha T_o x_q x_d'] \\ & + p^3[(2x_q x_d' + x_c\{x_q + x_d'\})T_o + r(x_d + x_q + rT_o) + \\ & \quad \alpha(2x_d x_q + \alpha x_q x_d' T_o) + 2\alpha r T_o(x_q + x_d')] \\ & + p^2[2x_d x_q + x_c(x_d + x_q) + r(T_o\{2x_c + x_q + x_d'\} + r) + \\ & \quad \alpha(T_o x_c\{x_q + x_d'\} + 2T_o x_q x_d' + \alpha x_d x_q) + \alpha r(2x_d + \\ & \quad 2x_q + 2T_o r + T_o\alpha\{x_q + x_d'\})] \\ & + p[T_o(x_c - x_q)(x_c - x_d') + r(x_d + x_q + 2x_c + rT_o) + \\ & \quad \alpha(x_c\{x_d + x_q\} + 2x_d x_q + \alpha x_q x_d' T_o) + \alpha r(2x_c T_o + 2r + \\ & \quad \alpha\{x_d + x_q\} + \alpha r T_o)] \\ & + [(x_d - x_c)(x_q - x_c) + r^2 + \alpha^2 x_d x_q + 2\alpha r x_c + (\alpha r)^2]\end{aligned} \tag{4d}$$

If the same generator as in reference 21 is taken, with $r = 0$, and the stability of the system as affected by α is studied by means of Routh's[24] criterion, the results of figure 18 are obtained. Also in a manner similar to that of reference 21 there is found an approximate formula for the lower region:

$$+\alpha^2 = \frac{(x_q - x_c)(x_d' - x_c)}{-x_q x_d'} \tag{5d}$$

or

$$x_c = \frac{x_q + x_d'}{2} \pm \sqrt{\frac{(x_q - x_d')^2}{4} - x_q x_d' \alpha^2} \tag{6d}$$

Similarly, an exact formula for the upper region is obtained by replacing x_d' by x_d in equation $5d$, whence

$$+\alpha^2 = \frac{(x_q - x_c)(x_d - x_c)}{-x_q x_d} \tag{7d}$$

or

$$x_c = \frac{x_q + x_d}{2} \pm \sqrt{\frac{(x_q - x_d)^2}{4} - x_q x_d \alpha^2} \tag{8d}$$

References

1. SERIES CAPACITOR INSTALLATION AT BALLSTON, N. Y., E. K. Shelton. *General Electric Review*, volume 31, August 1928, pages 432–4. SERIES CAPACITORS FOR TRANSMISSION LINES (BALLSTON, N. Y.), E. K. Shelton. *Elec. Engr. of Australia and N. Z.*, volume 5, October 15, 1928, pages 245–7.

2. APPLICATION AND PERFORMANCE OF SERIES CAPACITORS, M. I. Alimansky. *General Electric Review*, volume 33, November 1930, pages 616–25.

3. SERIES CAPACITOR IMPROVES 4,150 VOLT LINE OPERATION, W. S. Hill. *General Electric Review*, volume 36, October 1933, page 461.

4. WHY NOT SERIES CAPACITORS FOR DISTRIBUTION FEEDERS? C. L. Dudley and E. H. Snyder. *Electrical World*, volume 103, June 30, 1934, pages 942–5.

5. SERIES CAPACITORS, R. E. Marbury and W. H. Cuttino. *Electric Journal* volume 33, March 1936, pages 145–9.

6. LARGEST CAPACITOR BY INSTANTANEOUS RESPONSE ELIMINATES STUBBORN FLICKER, ORIGINATING IN INDUSTRIAL LOAD OFF RESIDENTIAL FEEDER, J. J. Lewis. *Electrical World*, volume 106, November 7, 1936, pages 3488–90.

7. SERIES CAPACITOR PROVES ECONOMICAL, A. E. Perreten. *Electrical West*, volume 77, December 1936, page 48.

8. IMPROVED VOLTAGE REGULATION WITH SERIES CAPACITORS, R. C. Buell. *General Electric Review*, volume 40, April 1937, pages 174–9.

9. EFFECT OF SERIES CAPACITORS UPON STEADY STATE STABILITY OF POWER SYSTEMS, E. S. Allen and J. L. Cantwell. *General Electric Review*, volume 33, May 1930, pages 279–82.

10. DIFFERENTIAL ANALYZER ELIMINATES BRAIN FAG, Irven Travis. *Machine Design*, July 1935, pages 15–18.

11. STABILITY OF SYNCHRONOUS MACHINES AS AFFECTED BY ARMATURE RESISTANCE, C. A. Nickle and C. A. Pierce. AIEE TRANSACTIONS, volume 49, June 1930, pages 338–350. Discussion, pages 350–1.

12. EFFECT OF ARMATURE RESISTANCE UPON HUNTING OF SYNCHRONOUS MACHINES, C. F. Wagner. AIEE TRANSACTIONS, volume 49, 1930, pages 1011–26. Also refer to discussion of reference 9.

13. LES RÉSEAUX DE TRANSMISSION D'ENERGIE (a book), Jean Fallou. Pages 390–408.

14. P. Boucherot, *Comptes Rendus des Séances*, Académie des Sciences, volume 170. Paris.

15. Jean Fallou, *Revue Générale de L'Electricite*, volume 19, June 1926, page 987.

16. THEORY OF ABNORMAL LINE-TO-NEUTRAL TRANSFORMER VOLTAGES, C. W. LaPierre. AIEE TRANSACTIONS, volume 50, March 1931, pages 328–42.

17. STUDIES IN NON-LINEAR CIRCUITS, C. G. Suits. AIEE TRANSACTIONS, volume 50, June 1931, pages 724–32.

18. STEADY STATE STABILITY OF COMPOSITE LOADS, S. B. Crary. ELECTRICAL ENGINEERING, volume 52, November 1933, pages 987–92.

19. FIELD TESTS TO DETERMINE THE DAMPING CHARACTERISTICS OF SYNCHRONOUS GENERATORS, F. A. Hamilton, Jr. AIEE TRANSACTIONS, volume 51, September 1932, pages 775–9.

20. TWO REACTION THEORY OF SYNCHRONOUS MACHINES WITH ANY BALANCED TERMINAL IMPEDANCE, C. Concordia. Submitted for publication.

21. TWO REACTION THEORY OF SYNCHRONOUS MACHINES, S. B. Crary. ELECTRICAL ENGINEERING (AIEE TRANSACTIONS), January 1937.

22. TRANSIENT PHENOMENA OF AN ALTERNATOR UPON CONDENSIVE LOAD, M. Takahashi. Researches of the Electrotechnical Laboratory, Tokyo, Japan, No. 350, August 1933.

23. TRANSIENT ANALYSIS OF ALTERNATING CURRENT MACHINERY, Y. H. Ku. *Journal of Electrical Engineering*, China, volume 3, number 4, August 1932, pages 179–206.

24. ADVANCED RIGID DYNAMICS (a book), E. J. Routh. Page 168.

25. TWO REACTION THEORY OF SYNCHRONOUS MACHINES, R. H. Park. Part I, AIEE TRANSACTIONS, volume 48, 1929, pages 716–27; part II, AIEE TRANSACTIONS, volume 52, 1933, pages 352–5.

Transformer Current and Power Inrushes Under Load

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Introduction

THE PHENOMENON of starting currents in transformers has been quite fully studied by several investigators,[1,2] especially when the transformer is without load. Little information, however, can be found in the technical literature on this subject when the transformer is loaded, let alone the effect of various load power factors.

This paper presents results of studies on starting currents and powers when loaded transformers are connected to their supply lines. Both primary and secondary switching are investigated, and unity, lagging, and leading load power factors are considered.

In this study the moving average is introduced as a means of analyzing oscillographic records. By its use the trends of the effective current and average power may be more readily observed. This in turn makes possible the determination of the primary transformer power factor variation during the transient period.

Galvanometer Connections

A schematic diagram of the galvanometer connections employed is shown in figure 1. The transformer used was a distribution-type transformer having similar primary and secondary windings designed for 220–110-volt operation. A one-to-one transformation ratio was used throughout the investigation. In the figure,

e represents the primary voltage galvanometer
i_p represents the primary current galvanometer
i_s represents the secondary current galvanometer
w represents the primary watt galvanometer

A special relay[3] developed for these studies was used for closing the primary or secondary circuit at the desired point on the primary voltage wave. In all cases of primary switching the core was completely demagnetized before the transformer was energized.

Figure 2 is a photograph of the laboratory setup showing all equipment in place.

No-Load Transients

Since the no-load starting current transient was needed for the predetermination of starting current transients with load, it is included herewith as oscillogram 1. In this oscillogram the circuit was closed on the zero of the voltage wave, this being the condition for maximum current inrush with zero residual flux. As previously mentioned, the transformer core was demagnetized before the switch was closed. Still larger values of starting current will result if positive residual flux is present at starting, and smaller values if negative residual magnetism is present. These extreme inrushes, however, are not considered in this paper because of the difficulty in controlling the magnitude of such residuals.

Predetermination of Starting Current Under Load

An approximate value of the maximum primary transient current under load (for zero residual flux) may be found by adding the primary no-load transient current of oscillogram 1 to a load component equal and opposite to the assumed secondary current. Greater accuracy, however, can be obtained by taking account of the effect of the increased iR drop in the primary winding due to the presence of the load component upon the magnetizing flux.

To include this effect the fundamental primary voltage equation,

$$Ri_m + N\frac{d\phi^*}{dt} = E_M \sin(\omega t + \lambda) \qquad (1)$$

must be modified thus,

$$R(i_m + i_L) + N\frac{d\phi}{dt} = E_M \sin(\omega t + \lambda) \qquad (2)$$

or

$$N\frac{d\phi}{dt} = E_M \sin(\omega t + \lambda) - R(i_m + i_L) \qquad (3)$$

Equation 3 shows that the induced voltage under load conditions differs from the induced voltage under no-load conditions by the factor Ri_L. This factor decreases the peaks of the magnetizing current. The extent of the decrease naturally depends upon the magnitude of i_L as well as upon its phase position.

Figure 3 shows 3 assumptions of load component currents. They represent, respectively, a unity power factor or resistance-load current, a 45-degree lagging or RL load current (with natural secondary transient d-c component), and a 50-degree leading or RC load current.

The adjusted no-load current component inrush may be determined by writing equation 3 as follows, and using the "finite difference method"

$$N\Delta\phi = [E_M \sin(\omega t + \lambda) - Ri_m]\,\Delta t - Ri_L\,\Delta t$$

* ϕ represents both the primary leakage flux and the mutual flux of the transformer.

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1. For all numbered references, see list at end of paper.

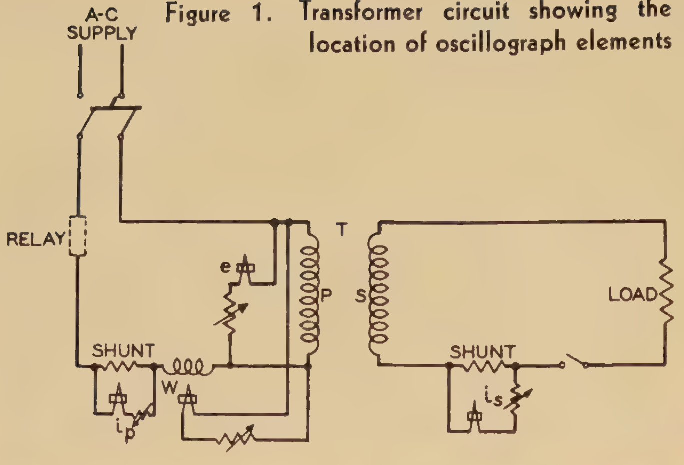
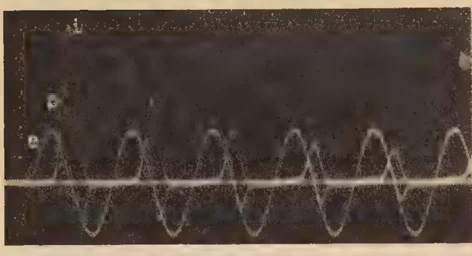


Figure 1. Transformer circuit showing the location of oscillograph elements

for each of the 3 load currents assumed and the corrected flux variations. The latter graphs show that the flux is only slightly reduced for the RC load, somewhat more for the R load, and still more for the RL load. The RL current is most effective in decreasing the positive flux values and increasing the negative values due to the d-c component in the secondary current and the resulting increase in

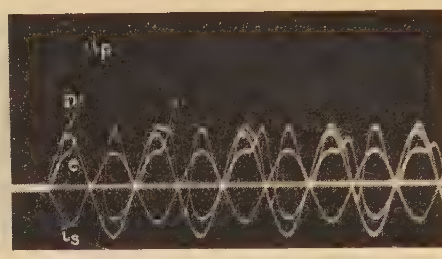
$$\sum Ri_L\Delta t$$

Naturally, this effect decreases as the d-c component dies out. In figure 5 are shown the corresponding magnetizing-current graphs. These values were obtained from the magnetization curve and correspond to the values of flux in figure 4.



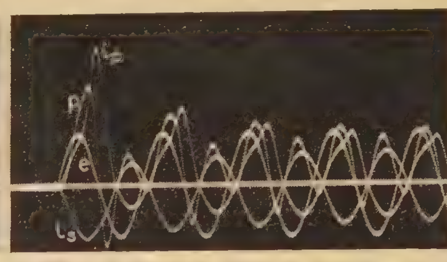
Oscillogram 1. The no-load current and power transient

e—Applied electromotive force (60 cycle)
i—Current p—Power
E (effective)—117 volts
Peak i—174 amperes Peak p—10.5 kw
Steady-state condition: P = 30 watts; I = 0.825 amperes
Transformer rating: 115 volts, 3 kva, 60 cycles



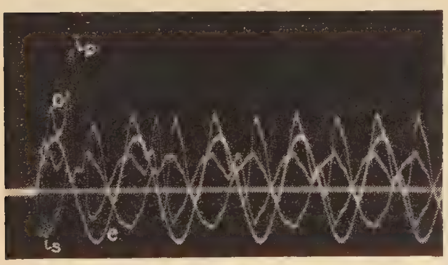
Oscillogram 2. Current and power delivered to a transformer connected to a unity-power-factor load, and energized at the time the voltage passes through zero

e—Applied electromotive force (60 cycle)
i_p—Primary current p—Primary power
i_s—Secondary current
E (effective)—113.5 volts
Peak i_p—160 amperes. Peak p—9,700 watts
Steady-state condition: primary power = 2,976 watts; primary current = 26.2 amperes; secondary current = 25.7 amperes; unity load power factor



Oscillogram 3. Current and power delivered to a transformer connected to a 0.700 lagging-power-factor load, and energized at the instant the supply voltage is zero

e—Applied electromotive force (60 cycle)
i_p—Primary current
p—Primary power
i_s—Secondary current
E (effective)—113 volts
Peak i_p—149 amperes
Peak p—10.4 kw
Steady-state condition: primary power = 2,160 watts; primary current = 26.6 amperes; secondary current = 25.8 amperes; load power factor = 0.700 lagging; ratio of transformation = 1



Oscillogram 4. Current and power delivered to a transformer connected to a 0.685 leading-power-factor load, and energized at the time the voltage wave passes through zero

e—Applied electromotive force (60 cycle)
i_p—Primary current
p—Primary power
i_s—Secondary current
E (effective)—115 volts
Peak i_p—162 amperes
Peak p—6,554 watts
Steady-state condition: primary power = 2,216 watts; primary current = 25.6 amperes; secondary current = 25.8 amperes; load power factor = 0.685 leading

This equation is the same as for the no-load condition with the exception of the $Ri_L\Delta t$ term. Therefore if the flux variation for the no-load transient is decreased by the summation of $Ri_L\Delta t$, from $t = 0$ to $t = t$, the flux variation under load may be found. The current corresponding to this corrected flux will be the magnetizing current for the load condition. Figure 4 shows the summations of $Ri_L\Delta t$

It now merely remains to combine the magnetizing and load component currents to obtain the total primary current. This was done in figure 6. Corresponding values from figures 3 and 5 were combined to give the resultant currents shown. Because of the effect of phase position the RL load peak now exceeds the no-load peak, whereas the R load is somewhat lower and the RC load is much lower, being only a little more than half of the RL peak value.

Oscillographic Verification

Oscillograms 2, 3, and 4 substantially confirm the anticipated load starting currents of figure 6. In each case the transformer core was demagnetized prior to the energizing of the transformer. Furthermore, in each of these oscillograms the primary circuit was closed on the zero value of the supply voltage, or when $\lambda = 0$. This created the maximum possible disturbance for zero residual flux.

The load was connected to its secondary before the primary circuit was closed.

An inspection of these 3 oscillograms shows that the secondary load current starts with approximately steady-state values. The primary currents in each case, however, contain a large transient component.

A comparison of actual and calculated values of the first loop with RL load is shown in figure 7. This shows substantial agreement between actual and predetermined values.

Primary Switching With λ = 90

When a transformer is in normal operation its flux is approximately zero when the impressed voltage is at its maximum value. Therefore, a demagnetized transformer connected to the line at the instant of maximum voltage will be under steady-state conditions from the start. Oscillograms 5, 6, and 7 illustrate this fact for unity, lagging, and leading power factors, respectively. Except for the difference in λ the conditions are the same as for oscillograms 2, 3, and 4. In the case of RL loading the secondary voltage was not exactly at its peak value and therefore a small d-c component is noticeable in the load current which in turn is reflected in the primary current. In the case of leading power factor the load consisted of R and C in parallel. This permitted the condenser to draw an abnormal current during the first quarter of a cycle.

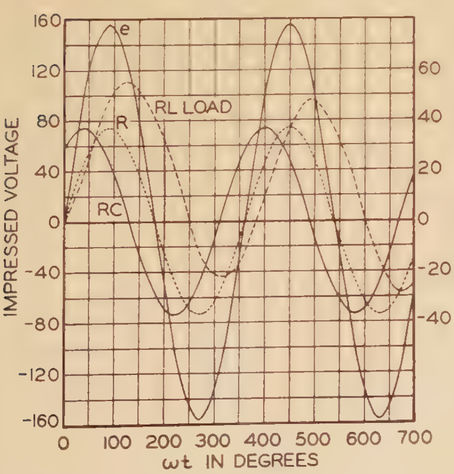
Figure 2. Transformer, oscillograph, wave point switch, meters, and load used in tests

Secondary Switching

In taking oscillograms numbers 8 to 13 inclusive, the primary circuit was first closed and the flux allowed to become normal before the secondary load circuit was closed. Any transient appearing in the primary will then be due to disturbances caused in the secondary circuit. Oscillograms numbers 8, 9, and 10 are for unity, lagging, and leading power factors when the secondary switch is closed at λ = 0, while 11, 12, and 13 are corresponding oscillograms for λ = 90.

In oscillograms 8 and 11 with resistance loading no transients are expected, and this is confirmed by the rec-

Figure 4 (right). Actual no-load and predicted load-flux variations



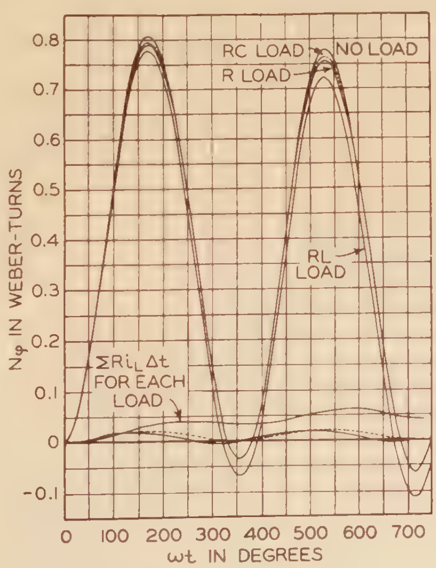


Figure 5 (below). Magnetizing component of primary current for 3 loads

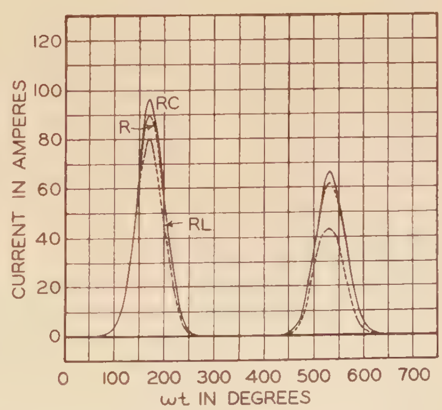
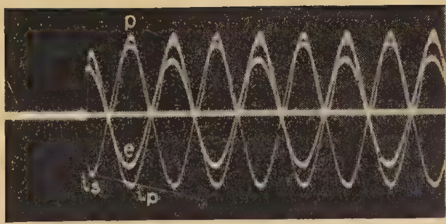
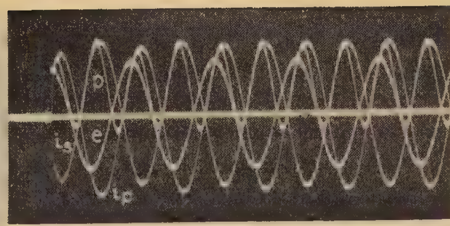


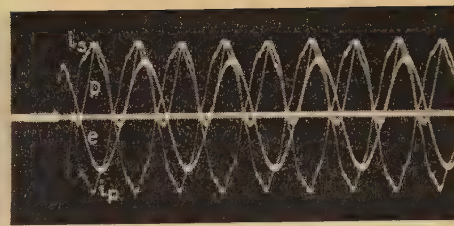
Figure 3 (left). Assumed primary load components. Effective value approximately 26 amperes. Power factors: unity, 45-degree lagging, and 50-degree leading



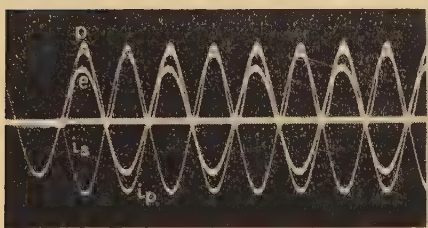
Oscillogram 5. Resistance loading. Primary switching at $\lambda = 90$ degrees; other conditions same as in oscillogram 2



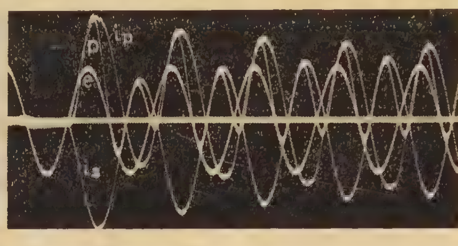
Oscillogram 6. Inductive loading. Primary switching at $\lambda = 90$ degrees; other conditions same as in oscillogram 3



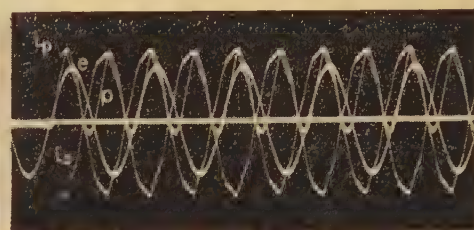
Oscillogram 7. Primary switching at $\lambda = 90$ degrees; other conditions same as in oscillogram 4



Oscillogram 8. Resistance loading. Secondary switching at $\lambda = 0$ degrees; other conditions same as in oscillogram 2



Oscillogram 9. Inductive loading. Secondary switching at $\lambda = 0$ degrees; other conditions same as in oscillogram 3



Oscillogram 10. Capacitive loading Secondary switching at $\lambda = 0$ degrees; other conditions same as in oscillogram 4

ords. In oscillogram 9, however, with RL loading and $\lambda = 0$ a large d-c component is present in the load current which is of course reflected in the primary current. In oscillogram number 13 the condenser draws a large initial current in an attempt to bring its q/C voltage up to the impressed electromotive force. A series RC connection would have partially avoided this difficulty.

Oscillogram Analysis

In oscillograms like those shown above, where the current and power variations are large and irregular, it is quite difficult to draw satisfactory conclusions. For this reason it was thought desirable to analyze them and make the current, power, and power factor trends more apparent. To this end the "moving average," long used by statisticians, was introduced as a means of ironing out the wide and irregular variations. It was applied in particular to oscillograms 2, 3, and 4.

The Moving Average Applied to Power

To apply this method of analysis to a power oscillogram, readings of instantaneous values of power were read and tabulated for 15-degree intervals from an enlarged oscillogram as shown in table I, columns 1 and 2. The first value under the heading Σp in column 3 is the sum of the instantaneous power ordinates for the first 360 degrees, and the first value in column 4 is the average

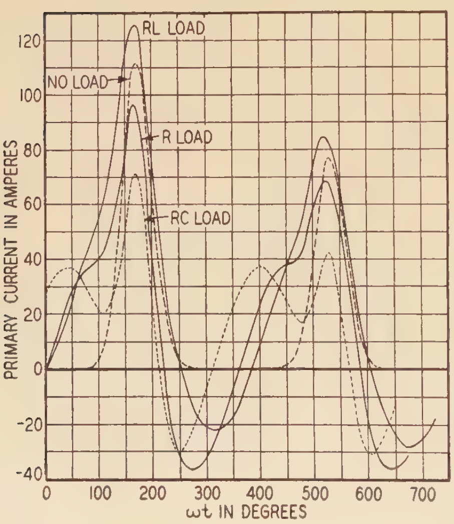


Figure 6. Predetermined total primary currents for 3 assumed loads

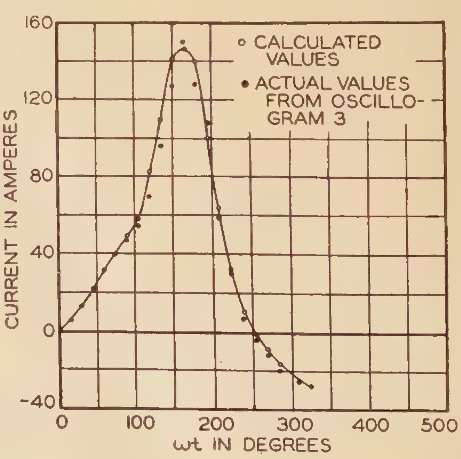


Figure 7. Comparison of actual and calculated values of primary current with RL load

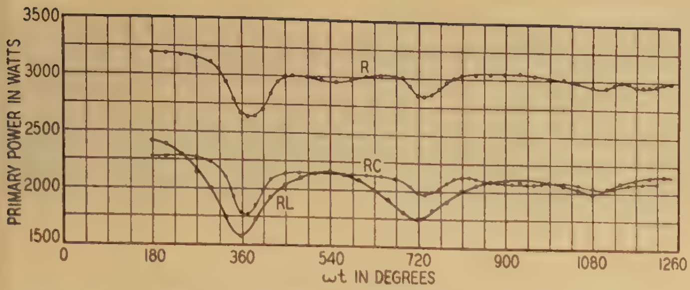


Figure 8. Trends of average values of primary power corresponding to oscillograms 2, 3, and 4

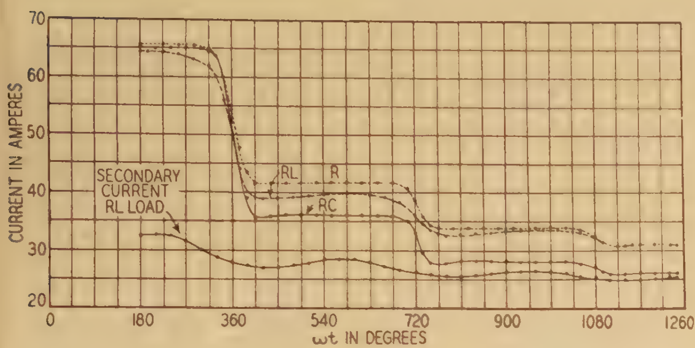


Figure 9. Trends of the effective values of primary current corresponding to oscillograms 2, 3, and 4

of these ordinates, and therefore the "average power." It is plotted in figure 8 as the average value of the power at 180 degrees. In like manner succeeding values of average power are obtained by averaging ordinates over a 360-degree span and plotting this value at the midpoint of the span. Figure 8 shows these values for a little over 3 cycles for oscillograms 2, 3, and 4. These graphs show the average power to remain fairly constant throughout the transient period. The *RL* and *RC* are less in value due to reduced values of power factor.

Table I. Calculations of Average Power and Power Factor

ωt	p	Σp	Average Power	Power Factor
0	0			
15	—			
30	560			
45	2,160			
60	3,840			
75	5,850			
90	7,580			
105	8,740			
120	9,850			
135	10,400			
150	9,480			
165	5,700	×10		
180 (−)	0	5,768	2,410	0.330
195	5,150	5,768	2,410	0.330
210	6,350	5,420	2,250	0.307
225	5,350	5,637	2,350	0.321
240	2,540	5,509	2,300	0.316
255 (+)	470	5,332	2,210	0.304
270	1,500	5,150	2,150	0.297
285	2,670	5,973	2,080	0.290
300	3,150	5,789	2,000	0.281
315	2,810	5,524	1,890	0.268
330	2,140	4,194	1,750	0.257
345	1,110	3,884	1,620	0.254
360 (−)	0	3,788	1,580	0.280
375	560	3,901	1,630	0.325
390	190	4,163	1,730	0.380
405 (+)	880	4,410	1,840	0.413
420	2,070	4,619	1,930	0.435
435	4,030	4,765	1,990	0.450
450	5,810	4,887	2,040	0.460
465	690	4,854	2,020	0.454

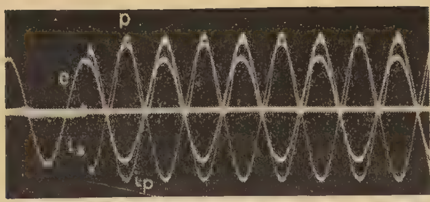
It is interesting to note that the average power during the transient period never goes to values higher than for steady-state values, in spite of the high peaks shown on the oscillogram. These high peak values represent power used in building up a magnetic field which is nearly all returned to the source.

Moving Average Applied to Current

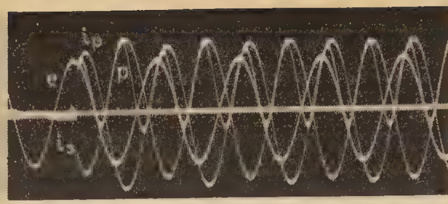
The procedure in finding the current trend is slightly different since the root-mean-square value is required and not the average. Instantaneous values for 15-degree intervals are read from the oscillogram and tabulated as shown in columns 1 and 2 table II. In column 3 the squared values are given. Column 4 is the sum of these squared values for 360 degrees, column 5 gives the average squared value, and column 6 the square root of this value, or the effective value. This value is plotted at the midpoint of the 360-degree span, namely at the 180-degree point. Succeeding values are obtained in the same manner. Values so obtained for oscillograms 2, 3, and 4 are plotted in figure 9 for about 4 cycles. This figure shows the currents to decrease in steps at the rate of one step per cycle. The total reduction is from a value of 65 amperes to the steady-state value of 26 amperes. The *RL* cur-

Table II. Calculations of Effective Current

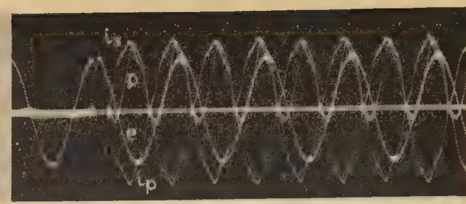
ωt	i	i^2	Σi^2	Average i^2	I
0	0	0			
15	4.4	19			
30	12.9	167			
45	22.2	493			
60	31.8	1,010			
75	39.9	1,590			
90	47.1	2,220			
105	56.0	3,140			
120	69.5	4,840			
135	95.2	9,070			
150	127	16,200			
165	149	22,200			
180	138	19,000	98,689	4,120	64.2
195	108	11,700	98,889	4,120	64.2
210	58.9	3,460	98,925	4,120	64.2
225	30.2	910	98,758	4,120	64.2
240	7.2	52	98,349	4,100	64.0
255	(−) 4.8	23	97,750	4,080	63.9
270	12.4	154	96,968	4,050	63.6
285	19.5	380	95,988	4,000	63.2
300	23.1	532	94,568	3,940	62.7
315	24.4	595	91,968	3,840	62.0
330	23	530	86,248	3,600	60.0
345	20.1	404	74,888	3,120	55.9
360	14.5	210	58,918	2,460	49.6
375	6.7	45	46,298	1,930	44
390	0	0	38,398	1,600	40
405	(+) 9.16	84	36,758	1,535	39.2
420	20.3	411	36,233	1,510	38.8
435	28.4	808	36,181	1,510	38.8
450	35.2	1,240	31,251	1,515	38.9
465	41.5	1,720	36,403	1,520	39.0



Oscillogram 11. Resistance loading. Secondary switching at $\lambda = 90$ degrees; other conditions same as in oscillogram 2



Oscillogram 12. Inductive loading. Secondary switching at $\lambda = 90$ degrees; other conditions same as in oscillogram 3



Oscillogram 13. Capacitive loading. Secondary switching at $\lambda = 90$ degrees; other conditions same as in oscillogram 4

rent decreases somewhat more rapidly due to the coincident decrease of the secondary current.

Transient Power Factor

After the effective current and average power are known the power factor can be calculated since the effective voltage is also known. The values of power factor corresponding to the current and power trends are tabulated in table I and plotted in figure 10. These graphs show

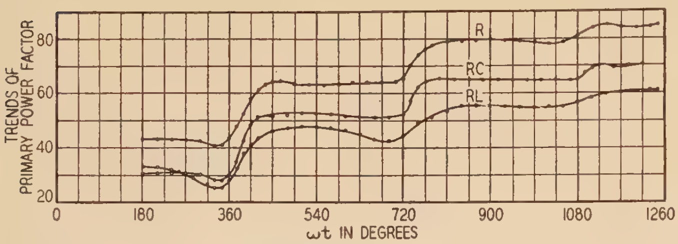


Figure 10. Trends of primary power factor corresponding to oscillograms 2, 3, and 4

that the power factors start with low values and increase in steps simultaneously with the decrease of the currents.

Conclusions

Some of the more important conclusions which may be drawn from this study can be briefly stated as follows:

1. The finite differences method will give satisfactory results when used to calculate transformer transients.

2. The load power factor has a decided effect upon the initial current and power variations in the case of loaded transformers.

3. The inductive load causes the maximum and the capacitive load the minimum disturbance in the primary current.

4. The effective value of the transient current, as calculated by the method of moving averages over a 360-degree span, decreases in steps.

5. The average power during the transient period, as calculated by the method of moving averages over a 360-degree span, does not vary much from its normal steady-state value.

6. The power factor is very low at the beginning of the transient and increases to its normal value in steps.

7. The magnetizing component of the primary current experiences little transient effect when a load is connected to the secondary.

References

1. Transient Currents in Transformers, H. M. Turner. Franklin Institute *Journal*, volume 211.

2. Starting Currents of Transformers, T. D. Yensen. University of Illinois Bulletin, No. 55.

3. Switch Makes Contact at Any Point on Wave, R. L. Witzke. *Electrical World*, February 13, 1937.

Some Effects of Welding on Ship Construction

SHIPBUILDING PRACTICE has been affected more in the last decade by the introduction and general adoption of welding than by any other one innovation, according to James B. Hunter in a paper presented during the spring meeting of The Society of Naval Architects and Marine Engineers at Chester, Pa., June 22, 1937. Design has been modified, particularly because a ship's hull must be assembled without annealing and so-called built-in stresses should be avoided as far as possible. The maximum amount of prefabrication on the ground or in the shop is desirable. Intricate forgings often can be replaced by simple welded parts, and welding is used extensively in parts for major machinery.

Erection and assembly procedure has been greatly modified by the use of welding, primarily because of the omission of holes and flanges for fastening individual members together and also because of the various methods adopted to take care of shrinkage and buckling, particularly on the lighter structures. In assembly, welding in most instances requires greater time because of sequence in order to avoid distortion and the introduction of so-called locked-up stresses. Such sequence usually entails completion of one section before starting work on the adjacent section. The greater amount of erection time directly affects shipyard capacity. Sheet-metal and pipe shops have also been affected greatly by the use of welding.

Different types of vessels require different methods and shop equipment. Welding has advanced recently to a great degree in the building of naval vessels, but in the design of this type the urge to save weight, because of treaty limitations, justifies increased cost, since military characteristics can be provided which would otherwise be impossible Such reasoning, however, cannot be applied to merchant vessels except in very special cases.

Magnetic Generation of a Group of Harmonics

By E. PETERSON MEMBER AIEE J. M. MANLEY NONMEMBER AIEE L. R. WRATHALL NONMEMBER AIEE

Synopsis

A harmonic generator circuit is described which produces a number of harmonics simultaneously at substantially uniform amplitudes by means of a nonlinear coil. Generators of this type have been used for the supply of carrier currents to multichannel telephone systems, for the synchronization of carrier frequencies in radio transmitters, and for frequency comparison and standardization.

A simple physical picture of the action of the circuit has been derived from an approximate mathematical analysis. The principal rôles of the nonlinear coil may be regarded as fixing the amount of charge, and timing the charge and discharge of a condenser in series with the resistance load. By suitably proportioning the capacity, load resistance, and saturation inductance of the nonlinear coil, the amplitudes of the harmonics may be made to approximate uniformity over a wide frequency range. The sharply peaked current pulse developed by condenser discharge passes through the nonlinear coil in its saturated state and so contributes nothing to the eddy-current loss in the core. In this way the efficiency of frequency transformation is maintained at a comparatively high value for the harmonics in a wide frequency band, even with small core structures. The theory has also been adequate in establishing a basis for design, and in evaluating the effects of extraneous input components.

I. Outline of Development

THE USE of nonlinear ferromagnetic core coils to generate harmonics started with a simple type of circuit due to Epstein[1] which appeared in 1902. Application of the idea was not made to any great extent until it was elaborated by Joly[2] and by Vallauri[3] in 1911. The frequency multipliers thus developed were limited to doublers and to triplers, polarization being required for the doubler. In these, as well as in subsequent developments, single and polyphase circuits were used, and various arrangements were adopted for the structure of the magnetic core and for the circuit, by which unwanted components were balanced out of the harmonic-output path. Later developments had to do with improvements in detail, and with the generation of higher harmonics in a single stage and in a series of stages. The applications of perhaps greatest importance were to high power, long-wave radiotelegraph transmitters, where the fundamental input was obtained from an alternator. Other applications of the idea of harmonic production by magnetic means have been made in the power and communication fields.[4]

It appears that these circuits were all developed primarily to generate a single harmonic. Comparatively good efficiencies were obtained, values from 60 to 90 per cent being reported for the lower harmonics. The theory of frequency multiplication was investigated by a number of workers, among whom may be mentioned Zenneck[5] and Guillemin.[6] The latter, after analysis which determined the optimum conditions for the generation of any single

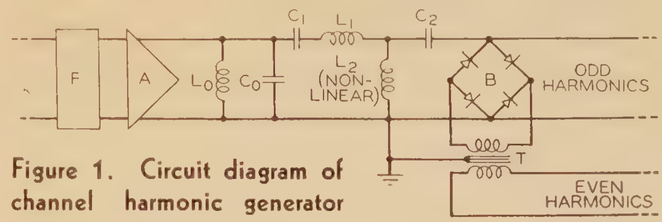


Figure 1. Circuit diagram of channel harmonic generator

harmonic, found experimentally that the efficiency of harmonic production decreased as the order of the harmonic increased. He obtained efficiencies of 10 per cent for the ninth harmonic, and 3 per cent for the thirteenth harmonic of 60 cycles.

Where the circuits are properly tuned and the losses low, free oscillations may be developed. The frequencies of these free oscillations may be harmonic, or subharmonic as in the circuit described by Fallou;[7] they may be rational fractional multiples of the fundamental, or incommensurable with the fundamental, as in Heegner's circuit.[8] The amplitudes of these free oscillations are usually critical functions of the circuit parameters and input amplitudes, and where the developed frequencies are not harmonic, they are characterized by the fact that the generated potentials are zero on open circuit. The theory of the effect has been worked out by Hartley.[9] It is presumably this effect which is involved in the generation of even harmonics by means of an initially unpolarized ferromagnetic core, an observation which has been attributed to Osnos.[10]

II. Circuit Description

The harmonic producer circuit which forms the subject of the present paper differs from those mentioned in that it is designed to generate simultaneously a number of harmonics at approximately the same amplitude.

Harmonics developed in circuits of this type have been used for the supply of carrier currents to various multichannel carrier telephone systems, for synchronizing carriers used in radio transmitters, and for frequency com-

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1. For all numbered references, see list at end of paper.

parison and standardization. Only odd harmonics are generated by the harmonic producer when the core of the nonlinear coil is unpolarized, as is the case here. To generate the required even harmonics, rectification is employed. This is accomplished by means of a well-balanced copper-oxide bridge, which provides the even harmonics in a path conjugate to the path followed by the odd harmonics.

A typical circuit used for the simultaneous generation of a number of odd and even harmonics at approximately equal amplitudes is shown schematically in figure 1. Starting with the fundamental frequency input, a sharply selective circuit F is used to remove interfering components, and an amplifier A provides the input to the harmonic generator. The shunt resonant circuit L_0C_0 tuned to the fundamental serves primarily to remove the second harmonic generated in the amplifier. The elements C_1L_1 are inserted to maintain a sinusoidal current into the harmonic producer proper, as well as to tune out the circuit reactance.

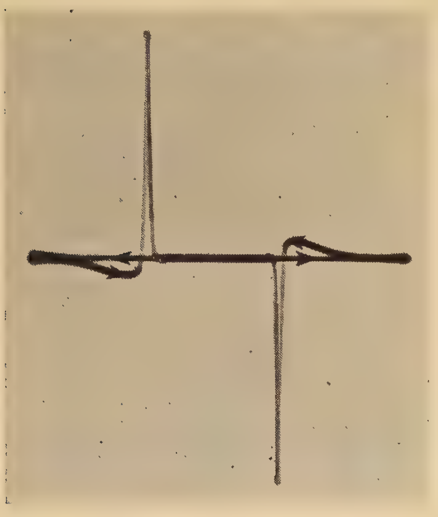


Figure 2. Cathode-ray oscillogram of output-current wave form with fundamental input current as abscissa

L_2 is a small permalloy core coil which is operated at high magnetizing forces well into the saturated region. The circuit including L_2, C_2, and the load impedance, which is practically resistive to the desired harmonics, is so proportioned that highly peaked current pulses rich in harmonics flow through it. Two such pulses, oppositely directed, are produced during each cycle of the fundamental wave, the duration of each being a small fraction of the fundamental period. The typical output wave shown in figure 2 was obtained by means of a cathode-ray oscillograph, the ordinate representing the current in the load resistance, and the abscissa representing the fundamental current into the coil. The desired odd harmonics are selected by filters connected across the input terminals of the copper-oxide bridge. The even harmonics are obtained by full-wave rectification in the copper-oxide bridge, and are taken off from the conjugate points of the bridge through an isolating transformer to the appropriate filters. Thus the harmonics are produced in 2 groups, with the even harmonics separated from the odds to a degree depending largely upon the balance of the copper-oxide bridge, as well as upon the amount of second harmonic passed on from the amplifier. In this way the required discrimination properties of any filter against adjacent harmonics are reduced to the extent of the balance.

A particular application of the circuit described above to the generation of carriers for multichannel carrier telephone systems uses a fundamental frequency of 4 kilocycles, from which a number of harmonics are developed. Of these the sixteenth to the 27th are used as carriers. A photograph of an experimental model of this carrier supply system (developed by Mr. J. M. West) is shown in figure 3. The top panel includes an electromagnetically driven tuning fork serving as the highly selective circuit F, the amplifier A, the output stage of which consists of a pair of pentodes in push-pull, and the tuned circuit L_0C_0. The next panel includes the elements L_1C_1, L_2, C_2, B, and T, together with a thermocouple and meter terminating in a cord and plug for test and maintenance purposes. The last 2 panels include the 12 harmonic filters, with test jacks and potentiometers for close adjustment of the output of each harmonic.

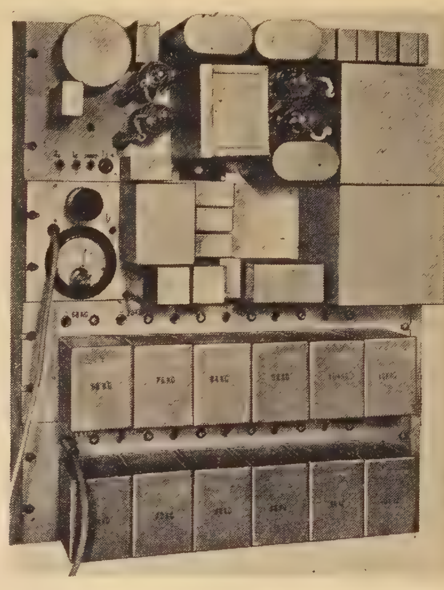


Figure 3. Carrier supply unit, furnishing 12 harmonics of 4 kilocycles (experimental model)

A few of the more interesting performance features are given in figure 4. The harmonic power outputs shown in figure 4a represent measurements at the input terminals of the filters. The variation observed is produced by the nonuniform impedance of the filters. When these are corrected, the variations due to the harmonic generator proper are less than ± 0.2 decibels from the sixteenth to the 27th harmonic. Outside this region the amplitudes gradually decrease to the extent of 4 decibels at the third and 35th harmonics, and 11 decibels at the fundamental and the 61st harmonic. The variation of harmonic output with change of amplifier plate potential is given for the 2 harmonics indicated in figure 4b. Figure 4c shows the 104-kilocycle output as a function of the 4-kilocycle input. Arrows are used to indicate normal operating points. The input amplifier is operated in an overloaded state so that,

beyond a critical input, the fundamental output of the amplifier and the harmonic output corresponding are but little affected by change of input amplitude. With a linear amplifier the harmonic output current would vary roughly as the 0.4 power of the input current.

Another application involving higher frequencies has been made to the generation of the so-called "group" carriers used in conjunction with a coaxial conductor.[11] There only odd harmonics of 24 kilocycles from the ninth to the 45th are required. These are generated at substantially uniform amplitudes. The circuit differs from figure 1 in that the copper-oxide bridge is omitted, and the nonlinear coil is provided with 2 windings to facilitate impedance matching. The performance of an experimental model is similar to that of the generator described above.

In both applications the required harmonics are generated at amplitudes high enough to avoid the necessity for amplification. A notion of the physical size and construction of the nonlinear coils used may be had from the photographs of figure 5.

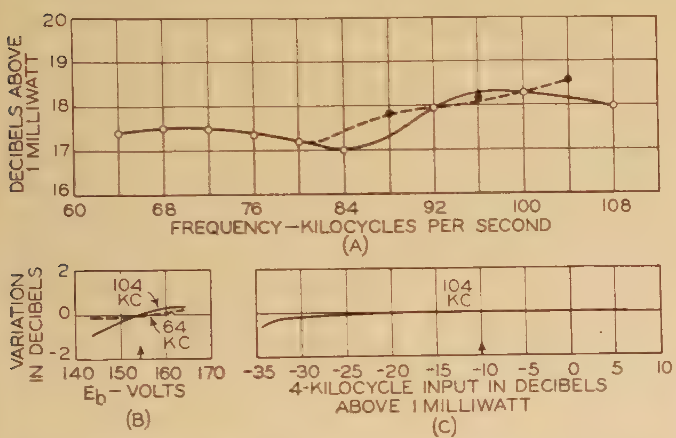


Figure 4. Performance curves of channel harmonic generator

A—Harmonic outputs

B—Variation of sixteenth and 26th harmonics with amplifier plate potential

C—Variation of 26th harmonic with fundamental input

III. Theory of Operation

The analysis of operation of the harmonic-generating circuit described above meets with difficulties, since a high degree of nonlinearity is involved in working the coil well into its saturated region.

To avoid these difficulties, an expedient is adopted by which the hysteresis loop is replaced by a single-valued characteristic made up of connected linear segments[6] as shown in figure 6*b*. It is then possible to formulate a set of linear differential equations with constant coefficients, one for each linear segment. The solutions are readily arrived at and may be pieced together by imposing appropriate conditions at the junctions, so that a solution for the whole characteristic is thereby obtained. From this solution the wave form of current or voltage associated with any circuit element may be calculated. Resolution of the wave form into components may then be accomplished by an independent Fourier analysis.

The assumed *B-H* characteristic of figure 6*b* is made up of but 3 segments. While it is manifestly a näive representation of a hysteresis loop, it will be shown by comparison with experiment that the main performance features of harmonic generators may be reproduced by this crude model.

It will be noted on figure 6*b* that the differential permeability of the assumed nonlinear core, a quantity proportional to dB/dH, takes on one of 2 values, determined by the absolute value of the magnetizing force. These are designated by μ in the permeable region and μ_s in the saturated region. The corresponding inductances are L_{20} and L_{2s}, L_{20} being many times greater than L_2. The values of current through the coil at which the differential inductance changes are designated $\pm I_0$, corresponding to the magnetizing forces $\pm H_0$. With this simple representation of the nonlinear inductance, the operation of the circuit shown in figure 6*a* will be described over a complete cycle of the fundamental input wave.

The current flowing in the input mesh is made practically sinusoidal by tuning L_1, C_1. If now we start at the negative peak of the sinusoidal input current of amplitude I_1 and frequency $p/2\pi$, the nonlinear coil is worked in the saturated state where its inductance L_{2s} is low. Since the resistance of the winding is small, the potential drop across the coil is correspondingly small. The current i_2 which charges the condenser C_2, assuming the latter to have zero

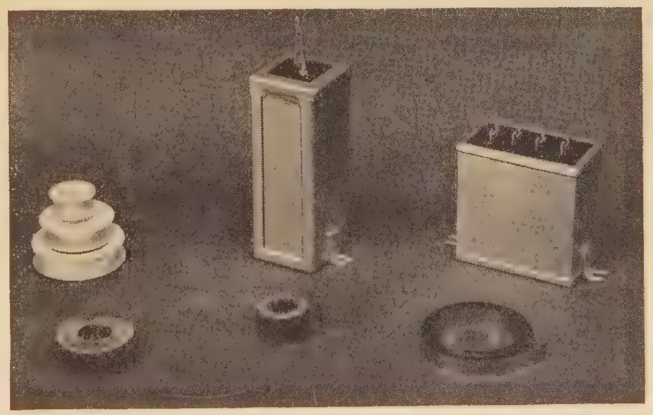
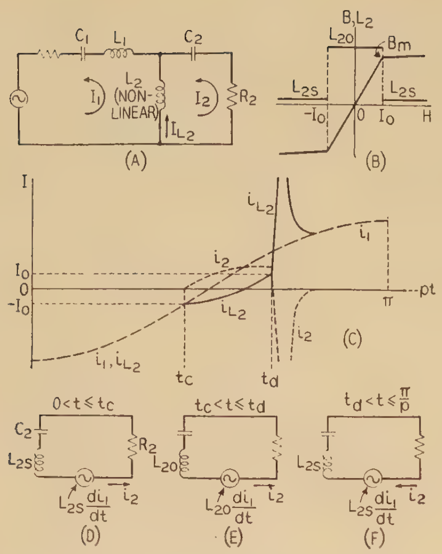


Figure 5. Construction of experimental nonlinear coils used for harmonic generation, showing core forms, magnetic tape, wound coils, and assembled units

charge at the start, is therefore negligible as indicated in figure 6*c*. This state of affairs is maintained until the current through L_2 reaches the value $-I_0$, at time t_c. At this point the inductance of the coil increases suddenly to L_{20} and the voltage across the coil tends to increase. Hence the current i_2 increases and C_2 is charged much more rapidly than in the preceding interval. Charging continues until the current through the coil increases through I_0 at time t_d. At that time, the coil inductance returns to



A—Harmonic generator circuit

B—Differential inductance and flux density of assumed nonlinear coil as functions of magnetizing force

C—Variation with time of currents in primary and secondary meshes, and in nonlinear coil

D, E, F—Equivalent circuits of the harmonic generator for the 3 time intervals indicated

Figure 6. Diagrams illustrating operation of the harmonic generator

the low saturation value L_{2s}, and the potential across the coil decreases. The condenser potential is no longer opposed by the potential drop across the coil and the condenser discharges through R_2 and L_{2s}; i_2 reverses its direction, maintaining the coil in the saturated region. The form and duration of the sharply peaked discharge pulse characteristic of this type of harmonic generator are determined by the values of the elements just mentioned. The resistance, capacity, and saturation inductance effectively in circuit are adjusted to permit the current to rise to a high maximum, to damp the pulse, and to shorten the pulse duration to the point at which the highest harmonic required reaches the desired amplitude. Under the working conditions which will be assumed in the following, this insures that the pulse dies away before the end of the half-cycle as shown in figure 6*c*. At that time the currents and potentials are the same, except for reversals of sign, as those at the start, so that the current wave consists of an alternating succession of these pulses. Equivalent circuits for the 3 respective time intervals of a half-cycle are shown in figures 6*d*, 6*e*, 6*f*. The similarity of the load-current wave form derived above, and that experimentally observed and shown in figure 2, is to be noted.

The course of events described above parallels closely conclusions drawn from the mathematical analysis. This picture attributes to the coil L_2 a sort of switching property which permits the condenser C_2 in the load circuit to be charged and discharged alternately. The charge starts when the large inductance L_{20} is switched across the primary and secondary meshes, thus permitting energy to flow from the primary circuit into the condenser C_2. This corresponds to that part of the wave described above during which the load current slowly rises as the charge accumulates on C_2. Discharge starts when the large inductance L_{20} is switched out and the much smaller inductance L_{2s} is switched in. This sharply reduces the voltage across L_2, and the condenser is discharged through the load resistance and the saturation inductance. During this interval the secondary circuit is practically isolated from the primary. The switching process is sustained by the alternations of the sinusoidal primary current and is periodic, as we have seen, since similar conditions exist at the start of each pulse. The times at which switching occurs are those at which the current through the coil passes through the critical values ($\pm I_0$) where the inductance changes.

Since the narrow discharge pulse provides the principal contribution to the higher harmonics in which we are interested; and since this charge takes place in the secondary independently of the primary, the elements of the secondary mesh during discharge determine the form of the output spectrum. From this viewpoint we may regard the condenser as the source of energy for these harmonics and hence as a possible location for equivalent harmonic generator electromotive forces. In this light, the discharge circuit becomes a half-section of low-pass filter terminated in resistance R_2, with L_{2s} as the series element and C_2 as the shunt element.

IV. Quantitative Results of Analysis

To connect the 3 solutions which hold for the 3 linear regions of the *B-H* characteristic, conditions at the junctions are introduced, which lead to transcendental equations. These may be solved graphically when definite values are assigned to the circuit parameters. From these may be obtained the maximum value Q_m of charge on C_2 which is reached at the end of the charging stage.

By plotting a representative group of these final charges over a range of parameters ordinarily encountered, an empirical equation has been deduced for Q_m as follows:

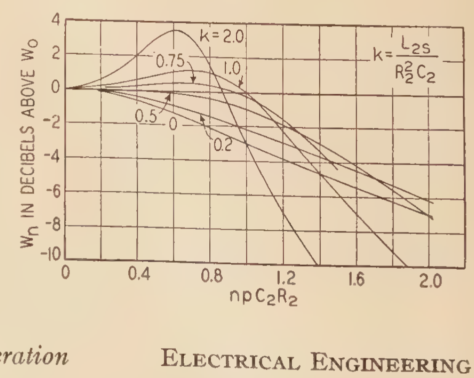
$$Q_m = \sqrt{2}\,\frac{I_1}{p}\left(\frac{pL_{20}}{R_2}\right)^{0.75}(pC_2R_2)^{0.65}\left(\frac{I_0}{I_1}\right)^{0.6} \qquad (1)$$

For the usual operating conditions the narrow peaked discharge part of the current pulse is most important in the determination of the higher harmonics (say beyond the ninth) with which we are concerned here. The charging interval then may be neglected in calculating the higher harmonics. The form of the discharge pulses is determined by the parameters pC_2R_2 and k, where

$$k = L_{2s}/R_2{}^2C_2$$

The familiar criterion for oscillation in a series circuit containing inductance, capacity, and resistance may be expressed in terms of k. If $k > {}^1/_4$, the discharge is an exponentially decaying oscillation; if $k \leq {}^1/_4$, the discharge is

Figure 7. Harmonic power spectrum plotted from equation 2 as function of npC_2R_2 with k as parameter



an exponentially decaying pulse. This last condition is the one assumed in the description of operation given above.

If the discharge is oscillatory, and if further the second peak is large enough, the current through the coil may become less than I_0 during the discharge interval. Thus L_2 will return to its larger value, and recharging of the condenser will result. This process may lead to large and undesired variations in the harmonic amplitudes. To maintain the frequency distribution as uniform as possible over the frequency range of interest, the circuit parameters are usually adjusted so that recharging does not occur.

Harmonic analysis shows that the nth harmonic amplitude under the above assumptions is given by

$$I(n) = \frac{(2/\pi)\, pQ_m}{\sqrt{1 + (1 - 2k)\,(npC_2R_2)^2 + k^2\,(npC_2R_2)^4}} \tag{2}$$

where n is odd. This expression neglects the contributions due to the charging stage, which are usually small for harmonics higher than the ninth.

The corresponding harmonic power output is

$$W_n = \frac{I(n)^2R_2}{2}\;\frac{W_0}{1 + (1 - 2k)\,(npC_2R_2)^2 + k^2\,(npC_2R_2)^4} \tag{3}$$

where W_0 is a convenient parameter which does not vary with n and hence serves as an indication of the power of the output spectrum. It is related to W, the total power delivered to the load resistance, by the equation

$$W_0 = \frac{4}{\pi}\, pC_2R_2W$$

For purposes of calculation W_0 may be found from (1) and (2) to be

$$W_0 = \frac{10^{-7}}{\pi^2}\, pB_m\, Ad\, H_1 \left(\frac{H_0}{H_1}\right)^{0.2} (pC_2R_2)^{1.3} \left(\frac{pL_{20}}{R_2}\right)^{0.5} \text{ watts} \tag{4}$$

where

$$L_{20} = \frac{4N^2A\mu 10^{-9}}{d}$$

$$H_1 = 0.4\, N\, I_1/d$$

$$H_0 = 0.4\, N\, I_0/d$$

and N is the number of turns wound on the toroidal core of diameter d centimeters and cross-sectional area A square centimeters.

In figure 7 the power spectrum is shown by plotting W_n in decibels above or below W_0 as a function of npC_2R_2 for several values of k. These curves illustrate the degree of uniformity obtainable in harmonic amplitudes under different conditions. It may be shown from (3) that W_n has a maximum with respect to n when k is greater than 1/2, if

$$npC_2R_2 = \frac{1}{k}\sqrt{k - \frac{1}{2}}$$

and that its value at this point is

$$(W_n)_{max} = W_0k^2/(k - {}^1/_4)$$

A number of relations may be derived from these equations which are useful for design purposes. Thus the form of harmonic distribution is fixed by k and pC_2R_2. The power for a given magnetic material worked at a given fundamental magnetizing force then depends solely upon the volume of core material. Finally, the impedance is fixed by the number of turns per unit length of core. If the impedances desired for primary and secondary circuits differ, separate windings may be used for each circuit.

V. Calculated and Observed Performance

In order to make practical use of the results given above, we need some basis for deriving the assumed parameters of the nonlinear coil from the physical properties of the magnetic materials used in harmonic producers.

The fact that the actual magnetization curve is a loop instead of a single-valued curve as assumed requires increased power input to the circuit to provide for the hysteresis and eddy losses in the core. Other than this, the principal remaining effect of the existence of a loop is a lag in the time at which the pulses occur, an effect which is of no great moment in determining the form or magnitude of the resulting pulses.

The next point requiring consideration is the effect introduced by the assumed abrupt change of slope contrasted to the smooth approach to saturation actually observed. While no rigorous comparisons can be drawn, the effect of the more gradual approach to saturation was approximated analytically by introducing an additional linear segment between the permeable region and each saturated region of the B-H characteristic, at a slope intermediate between the two, so as to form a B-H characteristic of 5 segments in place of the original 3. The solutions for these 2 characteristics were found to yield negligibly small differences in the amplitudes of the higher harmonics. It was inferred from this result that no substantial change would be introduced by a smooth approach to saturation.

Finally, the actual B-H characteristic has a slight curvature in the saturated region, while the analysis considered a small linear variation. A rough approximation for the effect of this curvature, which leads to fair agreement with experiment, consists in taking for L_{2s} the average of the actual slope, from its minimum value reached during the discharge peak down to the point at which the slope is ${}^1/_{10}$ maximum. To this is added the linear inductance contributed by the dielectric included within the winding.

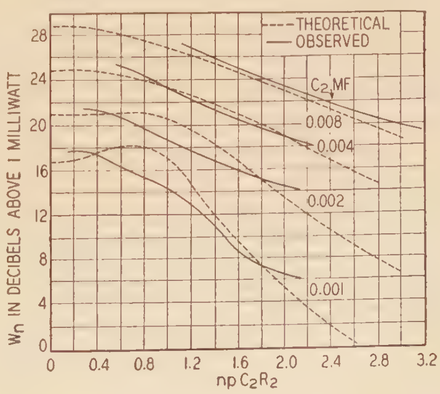


Figure 8. Comparisons of calculated and measured harmonic distributions, plotted as functions of npC_2R_2, with C_2 as parameter; fundamental (4-kilocycle) magnetizing force 8.1 oersteds

To summarize then, the harmonic outputs obtained from the analysis with the assumed B-H characteristic may be brought into line with experimental observations by the introduction of quantities obtained from actual B-H loops at appropriate frequencies and magnetizing forces. In these the maximum slope found on the loop is taken for L_{20}, the average slope over the saturated region is taken for L_{23}, and the energy corresponding to the area of the real B-H loop must be added to that originally supplied the harmonic generator input.

A comparison between measured and calculated harmonic distributions obtained with a 4-kilocycle fundamental input is shown in figure 8. In this case the harmonic distributions were measured for 4 different values of the secondary condenser C_2 as shown by the plotted points. The power output of each harmonic is plotted in terms of the quantity npC_2R_2. Calculated values are indicated by dashed lines. It is observed that while the agreement between calculation and experiment is perhaps as good as could be expected for the 2 highest curves, a substantial divergence is noticed in the 2 lowest sets; the forms of the 2 sets are significantly different, and it seems that the divergence might become even greater at larger values of npC_2R_2 than those shown. Upon examination of the equations, however, it turns out that the conditions existing for the lowest pair of curves are just those for which recharging occurs, so that the conditions for which the equations were framed hold no longer. The calculated distributions might be expected to be too low for the higher harmonics, since we have taken an average value for the saturation inductance. This means that the peak of the discharge pulse will be sharper than that calculated, with a corresponding effect upon the higher harmonics.

Another comparison between calculated and observed values is shown in figure 9 for a fundamental input of 120 kilocycles with 2 values of resistance load. Fair agreement is observed over the greater part of the frequency range, which extended to 5 megacycles. The distribution curve for the smaller resistance load undulates as the load resistance is reduced, since multiple oscillations and recharging are then promoted, in consequence of which the output power tends to become concentrated in definite bands of harmonics. In general, agreement within a few decibels is found over a wide range of circuit parameters when working into a resistance load, provided that recharging does not occur.

When the resistance termination is replaced by a bank of filters as it is in practice, the resistance termination is approximated over the frequency band covered by the filters. Where the band is wide the results obtained do not differ greatly from those with the pure resistance load, but when only a few harmonics are taken off by filters and the impedances to the other harmonics of large amplitude vary widely over the frequency range, then the wave form of the current pulse is substantially altered, with corresponding effect upon the frequency distribution, and the calculations for a pure resistance termination do not apply.

A difficulty sometimes arises in getting a desired value of fundamental current into the coil. Under certain circuit conditions the current amplitude is found to change rapidly as the input voltage is smoothly varied. This phenomenon has been described by various terms such as Kippeffekt, ferroresonance, and current-hysteresis.[13] If the operating point is located close to one of these discontinuities, the fundamental input and harmonic output may vary widely with small changes in supply potentials and circuit parameters. This troublesome source of variation may be avoided in a number of different ways, of which the simplest is to increase the resistance of the resonant mesh. In the present case this is effectively accomplished without sacrificing efficiency by using pentodes, which have high internal resistances, in the amplifier stage connected to the resonant mesh.

The efficiency of power conversion from fundamental to harmonics may be found from the fundamental power input to the circuit, as derived from measurements on a cathode-ray oscillograph, and from the total harmonic output measured by means of a thermocouple. The maximum efficiency obtainable with the low power circuits described in the second section is in the neighborhood of 75 per cent, and decreases with increasing fundamental frequency because of the increased dissipation due to eddy currents. It should be noted that this figure does not include losses in the primary inductance L_1. When only a few harmonics are used, the efficiency of obtaining this useful power naturally drops to a much lower value, which for the particular cases mentioned in the second section, is between 15 and 25 per cent.

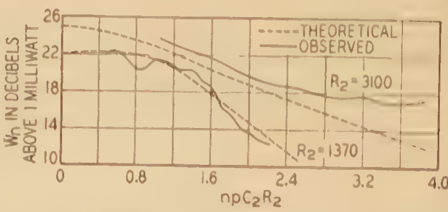


Figure 9. Comparisons of calculated and measured harmonic distributions, plotted as functions of npC_2R_2 with R_2 as parameter; fundamental (120 kilocycle) magnetizing force 9.8 oersteds

VI. Effect of Extraneous Components

In any practical case the fundamental input to the harmonic producer is accompanied by extraneous components introduced by crosstalk, by modulation, or by an impure source. Thus if the fundamental is derived as a harmonic of a base frequency, small amounts of adjacent harmonics will be present. Or if the amplifiers are a-c operated, side frequencies are produced differing from the fundamental by 60 cycles and its multiples. Extraneous components of this sort in the input modulate the fundamental and produce side frequencies about the harmonics in the output. When the harmonics are used as carriers, the accompanying products must be reduced to a definite level below the fundamental if the quality of the transmitted signal is to be unimpaired. The requirements imposed by this condition can be calculated by simple analy-

sis, the results of which agree rather well with experimental values.

The method of analysis used is to consider the extraneous component at any instant as introducing a bias[14] to the nonlinear coil. The primary effect of a small bias b is to shift the phase of the discharge pulse by $\mp b/H_1$ radians, H_1 being the amplitude of the fundamental magnetizing force. The sign of the shift alternates so that intervals between pulses are alternately narrowed and widened.

The effect of this shift on the harmonics produced may be found by straightforward means in which the amplitude of any harmonic is expressed in terms of the bias. Hence when the extraneous component or components vary with time, the sidebands produced may be evaluated when the bias is expressed by the appropriate time function.

If the bias is held constant, the wave is found to include both odd and even harmonics, the amplitudes of which are given by

$$\left.\begin{aligned} I_n &= I(n)\,|\cos nb/H_1| \quad (n \text{ odd}) \\ &= I(n)\,|\sin nb/H_1| \quad (n \text{ even}) \end{aligned}\right\} \qquad (5)$$

$I(n)$ being the harmonic distribution in the absence of bias as given by equation 2.

If the extraneous input component is sinusoidal, we have

$$b = Q \sin (qt + \phi) \qquad (6)$$

Substituting this expression for b in the equation for the harmonic components yields odd harmonics of the fundamental, and modulation products with the angular frequencies $mp \pm lq$, which may be grouped as side frequencies about the odd harmonics. The amplitude of the nth (odd) harmonic is

$$I_n = I(n)\left| J_0\left(\frac{nQ}{H_1}\right)\right| \qquad (7)$$

and the amplitude of the modulation product $mp \pm lq$ is

$$I_{m,\pm l} = I(m)\left| J_l\left(\frac{mQ}{H_1}\right)\right| \qquad (m + l \text{ odd}) \qquad (8)$$

where $J_l(x)$ is the Bessel function of order l.

Considering the side frequencies about the nth harmonic, the largest and nearest of these are $(n+1)p - q$ and $(n-1)p + q$, n being odd. The ratio of the amplitudes of either side frequency to the nth harmonic is

$$\frac{I_{n\pm 1,\mp 1}}{I_n} = \left|\frac{J_1[(n \pm 1)Q/H_1]}{J_0(nQ/H_1)}\right| \qquad (9)$$

on the assumption that the harmonic distribution in the neighborhood of n is uniform so that $I(n \pm 1) \doteq I(n)$. If the arguments of the Bessel functions are less than 0.4, a good approximation to the right member of equation 9 is $(n \pm 1)Q/2H_1$. Hence with sufficiently small values of interference, the sidebands produced are proportional to the amplitude of the interference, and increase linearly with the order of the harmonic. These relations apply to harmonic generators which produce sharply peaked waves in general, and are not peculiar to the magnetic types.

Neighboring modulation products involving the interfering component q more than once have much smaller amplitudes in normal circumstances than the product considered above. Because of the tuning in the input mesh, interfering components far removed in frequency from the fundamental are greatly reduced and the most troublesome interference is likely to be close in frequency to the fundamental.

It may be noted that where the interference is produced by amplitude modulation of the fundamental, so that 2 interfering components enter the input, the distortion

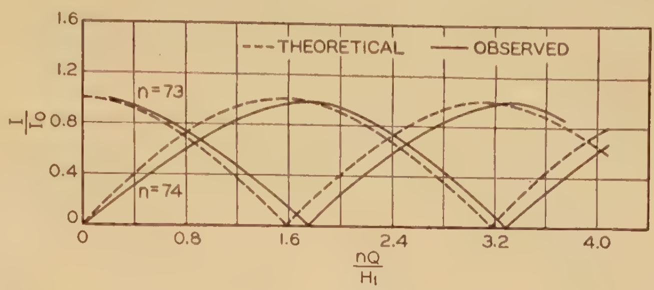


Figure 10. The 73rd and 74th harmonic amplitudes as functions of direct current flowing through nonlinear coil. Ordinate is ratio of harmonic amplitude, with bias indicated, to that of 73rd harmonic with zero bias; abscissa is harmonic number multiplied by the ratio of bias to fundamental; dashed lines calculated from equation 5, full lines measured; fundamental 4 kilocycles

produced may be approximated by doubling the amplitudes of the side frequencies produced by one of the interfering components. If the disturbance is the second harmonic of the fundamental, the effect is nearly the same as that for constant bias, and the relations (5) may be used if b is taken as the amplitude of the second harmonic magnetizing force.

To illustrate the effects of d-c bias, figure 10 shows the amplitudes of the 73rd and 74th harmonics of 4 kilocycles as functions of the parameter nQ/H_1. The agreement between measured and calculated values indicates that the most important effects of bias have been included in the simple analysis.

References

1. *E.T.Z.*, volume 25, 1904, page 1100.
2. *C.R.*, volume 152, 1911, page 856.
3. *E.T.Z.*, volume 32, 1911, page 988.
4. Cantwell, ELECTRICAL ENGINEERING, July 1936, page 784.
5. I.R.E. *Proc.*, volume 8, 1920, page 468.
6. *Arch. f. El.*, volume 17, 1926, page 17 and I.R.E. *Proc.*, volume 17, 1929, page 629.
7. *Rev. Gen. d'El.*, volume 19, 1926, page 987.
8. *Zeit. f. Fernmeldetechnik*, volume 5, 1924, page 115.
9. Peterson, *Bell. Lab. Record*, February 1929, page 231.
10. Kasarnowski, *Zeit. f. Phys.*, volume 30, 1924, page 225.
11. Espenschied and Strieby, ELECTRICAL ENGINEERING, October 1934, page 1371.
12. Elmen, ELECTRICAL ENGINEERING, December 1935, page 1292.
13. Casper, Hubmann, and Zenneck, *Jahrbuch*, volume 23, 1924, page 63. Rouelle, *C.R.*, volume 188, 1929, page 1392.
14. Peterson and Llewellyn, I.R.E. *Proc.*, volume 18, 1930, page 38.

Transmission Lines at Very High Radio Frequencies

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Summary

Radiation resistance, although ordinarily neglected, is actually of dominant importance in determining the selectivity factor Q and the input impedance Z_s for both parallel-wire and concentric lines at high radio frequencies, and therefore materially changes the optimum design of the line, whether used as a low-loss inductive or capacitive reactance or to give high selectivity or high impedance as a resonant line. Accurate design equations for maximum selectivity and for maximum impedance are developed in this paper for both parallel-wire and concentric lines, and curves are included showing radiation resistance, selectivity, input impedance, optimum values of spacing, conductor radius, etc. It is shown that for maximum Q the optimum ratio of spacing to wire radius for parallel-wire lines is $D/r = 6.186$, and the ratio of outer conductor radius to inner conductor radius for concentric lines is $b/a = 4.22$, as compared with values of about 3.6 for both ratios when radiation resistance is neglected. For maximum impedance corresponding values are $D/r = 20.96$ and $b/a = 14.3$, as compared with values of 8 and 9.2, respectively, predicted neglecting radiation resistance. Moreover, Q and Z_s are not proportional to D and b, as indicated in previous analyses; instead definite values of D and b give maximum Q and slightly larger values give maximum Z_s, and even a small departure from the best value produces a large decrease in Q or in Z_s. Q and Z_s for optimum design are both *inversely* proportional to the cube root of the frequency for parallel-wire lines and inversely proportional to the 0.4 power of the frequency for concentric lines, whereas previous analyses showed both *increasing* as the square root of the frequency.

Introduction

RADIO COMMUNICATION in recent years has experienced a greatly increased utilization of the ultrahigh frequencies (those above 30,000,000 cycles), and the near advent of television will undoubtedly make these frequencies among the most valuable and most used in the entire spectrum. At these very high frequencies resonant transmission lines offer advantages in many ways which are not even closely approached by their nearest competitors. For instance the oscillating crystal, almost invariably used at lower frequencies to give radio transmitters a high degree of frequency stability, can be used at ultrahigh frequencies only in conjunction with several stages of frequency multiplication, since the Q of the crystal (the ratio of its inertia reactance to its frictional resistance, and therefore a measure of its frequency stabilizing ability) is inversely proportional to frequency and assumes such a low value at the ultrahigh frequencies as to be practically worthless for frequency stabilization. For instance at 30,000,000 cycles the Q of an X-cut quartz crystal is approximately 170, and at 300,000,000 cycles it is only about 17. To obtain values even as high as these requires careful mounting to keep the external work done by the oscillating crystal as small as possible. On the other hand, properly designed resonant transmission lines at these frequencies are extremely selective. For instance at 300,000,000 cycles as short-circuited quarter-wave parallel-wire line (approximately 10 inches long) of number 10 copper wire spaced 0.32 inch between wire axes has a Q of 771. A concentric line of the same length and of optimum design has a Q of 4,560. (The Q of any electrical circuit is defined as

$$Q = \frac{2\pi f L}{R} = \frac{2\pi c L}{\lambda R} = \frac{2\pi L}{\lambda R\sqrt{LC}} = \frac{2\pi Z_0}{\lambda R}$$

where R, L, and C are respectively resistance, inductance, and capacity per unit length of 2-wire line, $c = 1/\sqrt{LC} = 3 \times 10^{10}$ centimeters per second is the velocity of propagation of an electromagnetic wave in space and, at the ultrahigh frequencies, also the velocity along a wire, λ is the wave length in centimeters and equals c/f, and $Z_0 = \sqrt{L/C}$ is the characteristic impedance of the line.) Evidently at the ultrahigh frequencies a comparatively tiny resonant line can give frequency stabilization far superior to that obtained by means of a crystal and at a small fraction of the expense. The high Q of such lines also gives them a unique place as voltage step-up devices, the step-up ratio for an open-circuited quarter-waveline equaling $4Q/\pi$. Thus at 300,000,000 cycles, at which frequency the ordinary tuned radio-frequency transformer is of little value, a quarter-wave open-circuited concentric line gives a voltage step-up of 5,810.

Moreover, the high impedance obtainable by the use of resonant lines makes them ideally adapted as coupling elements between stages of vacuum-tube amplifiers at these high frequencies. Approximately a million ohms resistance may readily be obtained by means of a shorted quarter-wave concentric line. The quarter-wave line is also used extensively as an impedance matching device,[1] as a means of holding current at the receiving end of the line constant regardless of large changes in the magnitude and angle of the load impedance,[2] and as an impedance inverting device.[3]

A short-circuited transmission line of less than a quarter wave length acts as a high-quality low-loss inductive re-

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1. For all numbered references, see list at end of paper.

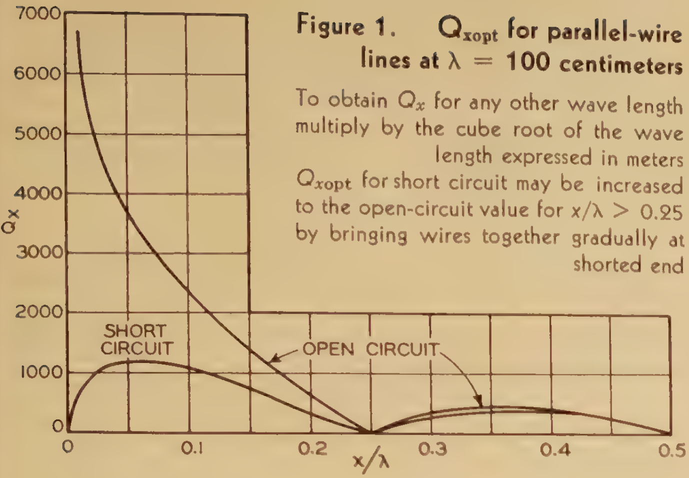


Figure 1. Q_{xopt} for parallel-wire lines at λ = 100 centimeters

To obtain Q_x for any other wave length multiply by the cube root of the wave length expressed in meters

Q_{xopt} for short circuit may be increased to the open-circuit value for $x/\lambda > 0.25$ by bringing wires together gradually at shorted end

actance with a Q at the ultrahigh frequencies far superior to that of any coil. An open-circuited line of less than a quarter wave length acts as a high Q capacitive reactance. If a capactive reactance which will pass direct current is desired, a short-circuited line of about $^3/_8$ wave length may be used, preferably a concentric line. Transmission lines, especially those of the concentric type, are therefore ideally adapted for use as circuit elements for electric filters and as tuning devices in general at ultrahigh frequencies.

The use of transmission lines as circuit elements at ultrahigh frequencies has been considered in several previous papers, of which Terman's "Resonant Lines in Radio Circuits," published in Electrical Engineering, July 1934, is the most comprehensive. However, in all of these papers the effect of radiation resistance in altering the effective resistance of both parallel-wire and concentric lines has been neglected. In addition, the effect of proximity of the 2 wires in a parallel-wire line, in altering the constants L, C, and R, and therefore the input impedance and the Q of the line although mentioned in some of the papers, has not been taken into account with rigid mathematical accuracy. The proximity effect is small for the optimum ratio of spacing to wire radius, decreasing L and Z_0 by about 1.5 per cent each, increasing C by about 1.5 per cent, and increasing R by about 5.5 per cent. Of course there is no proximity effect in a concentric line. Consideration of these factors, and especially of the radiation resistance, very materially changes the optimum design of the line, whether used as a low-loss inductive or capacitive reactance or to give high selectivity or high impedance as a resonant line.

Specifically the following changes are introduced:

1. When radiation and the proximity effect are neglected, the analysis *seems* to show that both the resonant input impedance Z_s and the resonant Q are directly proportional to the square root of the frequency for both parallel-wire and concentric lines. That is, the analysis appears to show that Q *increases* as frequency increases. However, when radiation resistance and the proximity effect are taken into consideration it is found that for parallel-wire lines Q is *inversely* proportional to the cube root of the frequency, and for concentric lines is inversely proportional to the 0.4 power of the frequency. In other words, Q actually *decreases* as frequency increases for both parallel-wire and concentric lines.

2. When radiation resistance and the proximity effect are neglected, the analysis seems to show that the resonant Q and Z_s are proportional to the spacing for parallel-wire lines, and proportional to the outer diameter for concentric lines, and designers have therefore been urged to use large values of spacing and diameter, respectively. Taking radiation resistance and the proximity effect into account, however, shows that for any frequency and length of line a definite spacing for parallel-wire lines and a definite outer diameter for concentric lines give maximum Q, and slightly larger values of spacing and outer diameter, respectively, give maximum values for Z_s. Moreover these values, in general, especially for the very high frequencies, are considerably smaller than the values which have been recommended on the basis of the older analysis, and even a small departure from the best value produces a relatively large decrease in Q or in Z_s.

3. Disregarding radiation resistance and the proximity effect gives a false optimum value of D/r = 2.72 for a parallel-wire line, and b/a = 3.6 for a concentric line to give maximum Q.
D is spacing between wire axes for parallel wires,
r is wire radius for a parallel-wire line,
b is inner radius of outer tube of a concentric line, and
a is outer radius of inner conductor.

Taking radiation resistance and the proximity effect into account changes these values to

D/r = 6.186 for parallel-wire lines
b/a = 4.22 for concentric lines
} Optimum values for maximum Q for a line of any length, whether resonant or not

4. Disregarding radiation resistance and the proximity effect, the analysis seems to show that Q is independent of the number of quarter wave lengths of line used and of the line termination. Actually Q is a function of line length and in general is quite different for open-circuit than for short-circuit termination.

5. Disregarding the radiation resistance and the proximity effect gives a false optimum value of D/r = 8 for a parallel-wire line, and b/a = 9.2 for a concentric line if maximum input impedance is desired. Taking radiation resistance and the proximity effect into account changes these values to

D/r = 20.96 for parallel-wire lines
b/a = 14.3 for concentric lines
} Optimum ratios for maximum Z_s at resonance

The higher the frequency the more important radiation resistance becomes. For instance, at 300,000,000 cycles the analysis, disregarding radiation resistance and proximity effect, would seem to show that a parallel-wire line, a quarter wave length long and short-circuited, would have a Q of 2,655 if constructed of wires 0.5 inch in diameter

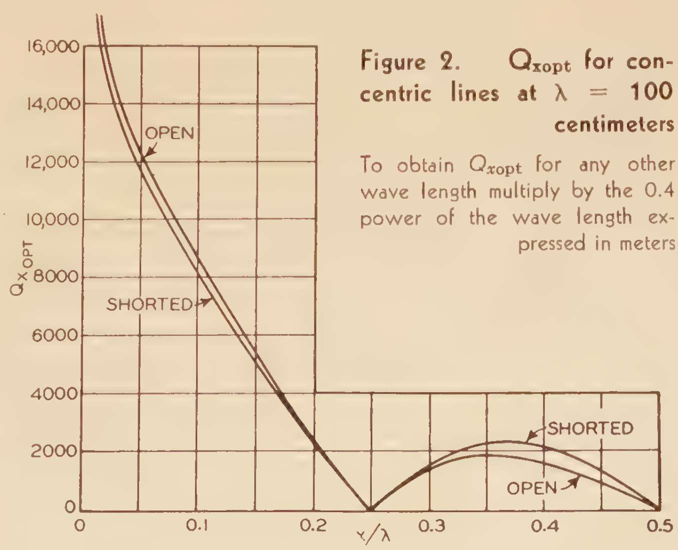


Figure 2. Q_{xopt} for concentric lines at λ = 100 centimeters

To obtain Q_{xopt} for any other wave length multiply by the 0.4 power of the wave length expressed in meters

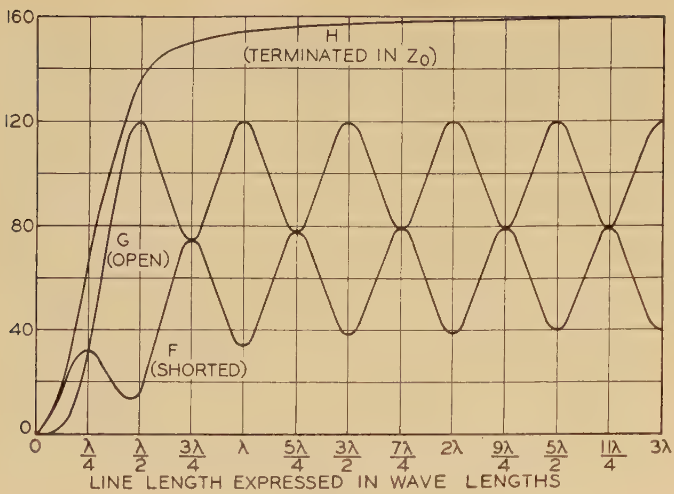


Figure 3

Multiply by $(\pi D/\lambda)^2$ to obtain radiation resistance for parallel-wire lines

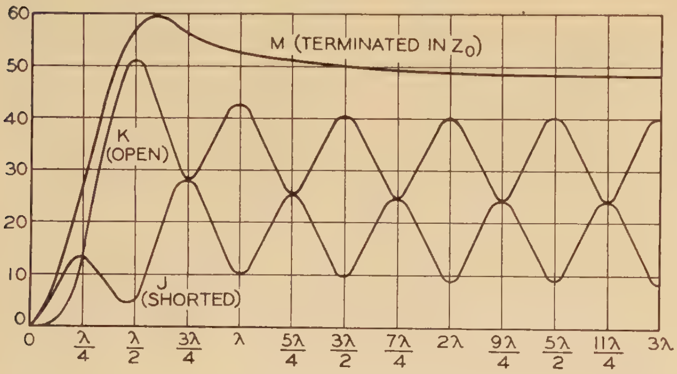


Figure 4

Multiply by $(\pi^4/\lambda^4)(b^2 - a^2)^2$ to obtain radiation resistance for concentric line

and spaced 0.68 inch between wire axes. Actually, however, the neglected radiation resistance in this case is almost 8 times as large as all other resistance. The correct value of Q is only 423. If, however, the diameter of the wire is *decreased* to 0.262 centimeter (0.103 inch) and the spacing to 0.812 centimeter (0.319 inch), the optimum values for this frequency, a Q of 771 is obtained. If, instead of using a shorting bar to short the line, the 2 wires are brought together gradually, this Q can be increased to over 1,000. Both diameter and spacing must, however, be increased about 50 per cent over the values given above.

Similarly for a quarter-wave short-circuited concentric line to be operated at 60,000,000 cycles Hansell and Carter (April 1936, IRE *Proceedings*, page 599) recommend values of $b = 30$ centimeters (11.8 inches) and $a = 8.25$ centimeters (3.25 inches). Neglecting radiation resistance they compute that the Q of the line would equal 20,000. Actually here also the effect of the radiation resistance, which was neglected, is approximately 5.6 times as large as that of all other resistance. So, instead of a $Q = 20{,}000$, it actually is only 3,420. If the optimum design, considering radiation resistance, had been used, the b and a could have been decreased to 16.95 centimeters and 4.02 centimeters respectively, which would have raised Q for the quarter-wave shorted line to 8,680. Moreover, if a half-wave concentric line, shorted at both ends and fed at any intermediate point on the line, had been used the Q could have been raised to 12,000.

Fundamental Transmission Line Equations

Whether a transmission line is to be used to carry hundreds of thousands of kilowatts at commercial power frequencies, or fractions of a watt at the audio frequencies as in a telephone line, or power in varying amounts at radio frequencies, the same equations, derived in many textbooks (see Woodruff's "Electric Power Transmission and Distribution") hold accurately, namely

$$\left.\begin{aligned} E_s &= E_r \cosh px + I_r \sinh px \\ I &= I_r \cosh px + \frac{E_r}{Z_0} \sinh px \\ Z_s &= E_s/I_s \end{aligned}\right\} \quad (1)$$

where

E_r and I_r are voltage and current respectively at the receiving or load end of the line,
E_s and I_s are voltage and current at the sending end of the line,
x is length of line (in our work the unit of length is the centimeter),
$p = (\alpha + j\beta)$ is the propagation constant per unit length of line,
α is the attenuation constant per unit length of line,
β is the wave length constant per unit length of line,
$Z_0 = \sqrt{Z/Y}$ is the characteristic impedance of the line,
Z is the series impedance per unit length of line,
Y is the admittance between conductors per unit length of line.

At high radio frequencies

$$\alpha = \frac{R}{2}\sqrt{\frac{C}{L}} = \frac{R}{2Z_0}$$

$$\beta = \frac{2\pi}{\lambda}$$

where λ(lambda) is the wave length.

If the wave length is expressed in centimeters, $\lambda = 3 \times 10^{10}/f$, where f is frequency.

The Line as a Low-Loss Inductive or Capacitive Reactance

For open circuit, $I_r = 0$, so

$$Z_s = \frac{E_r \cosh px}{\frac{E_r}{Z_0}\sinh px} = Z_0 \frac{\cosh \alpha x \cos \beta x + j \sinh \alpha x \sin \beta x}{\sinh \alpha x \cos \beta x + j \cosh \alpha x \sin \beta x}$$

Eliminating the j term from the denominator by multiplying by

$$\frac{\sinh \alpha x \cos \beta x - j \cosh \alpha x \sin \beta x}{\sinh \alpha x \cos \beta x - j \cosh \alpha x \sin \beta x}$$

and collecting terms gives

$$Z_s = Z_0 \frac{(\alpha x - j \cos \beta x \sin \beta x)}{(\alpha x)^2 \cos^2 \beta x + \sin^2 \beta x} \quad (2)$$

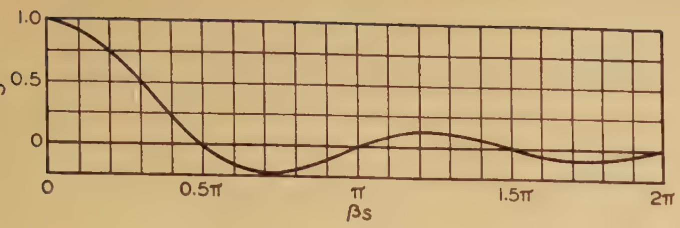


Figure 5. S versus βs

$S = (\sin 2\beta s)/2\beta s$

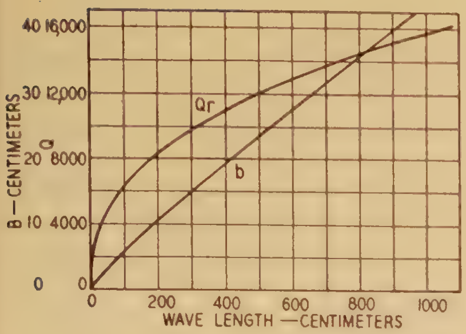


Figure 6. Optimum Q_r and b versus λ for half-wave concentric line shorted at both ends and fed at any intermediate point

since for x only a few wave lengths long, αx at the ultra-high frequencies is so small that cosh αx = 1.0 and sinh $\alpha x = \alpha x$ (both ordinarily within one part in 10^6). Except for x *very* close to $n\lambda/2$, where n is any integer, $(\alpha x)^2$ is negligible compared with $\sin^2 \beta x$, and

$$Z_s = Z_0\left(\frac{\alpha x}{\sin^2 \beta x} - j \operatorname{ctn} \beta x\right) = Z_0 \operatorname{ctn} \beta x\left(\frac{Rx}{Z_0 \sin 2\beta x} - j\,1.0\right) \tag{3}$$

Evidently such a line acts as a condenser with a $Q_r = (Z_0 \sin 2\beta x)/Rx$.

Note: We differentiate throughout the paper between the Q of a line acting as an inductive or capacitive reactance, which we designate Q_x, and the Q of the resonant line, which we designate Q_r. In general, the 2Q's have very different values.

Example: For a parallel-wire line, for λ = 100 centimeters (f = 300,000,000 cycles), and $x = \lambda/20$ = 5 centimeters, with optimum radius of wire and spacing for minimum loss,

Z_0 = 215.2 ohms
Z_s = 661 (0.000266 − j 1.0)
Q_x = 3,750 (from curve in figure 1)

Similarly for short circuit

$$Z_s = Z_0 \frac{\alpha x + j \sin \beta x \cos \beta x}{\cos^2 \beta x + (\alpha x)^2 \sin^2 \beta x} \tag{4}$$

Except for x *very* close to $(2n+1)\lambda/4$, $(\alpha x)^2$ is negligible compared with $\cos^2 \beta x$, so

$$Z_s = Z_0\left(\frac{\alpha x}{\cos^2 \beta x} + j \tan \beta x\right) = Z_0 \tan \beta x\left(\frac{Rx}{Z_0 \sin^2 \beta x} + j\,1.0\right) \tag{5}$$

Thus a short-circuited line, less than a quarter wave length long, acts as an inductive reactance with a $Q_x = (Z_0 \sin 2\beta x)/Rx$.

Example: For a parallel-wire line, for λ = 100 centimeters, and x = 5 centimeters, if line is designed for minimum loss, then

Z_0 = 215.2 ohms
Z_s = 69.9 (0.000867 + j 1.0)
Q_x = 1,154 (from curve in figure 1)

Example: For a concentric line, and same λ and x as above,

Z_0 = 86.4 ohms
Z_s = 28 (0.0000865 + j 1.0)
Q_x = 11,550 (from curve in figure 2)

Compare this Q_x with a Q of about 17 for a quartz crystal at this frequency.

Equations for Resonant Lines

When an open-circuited line is *very* nearly any multiple of a half wave length long, equation 2 is evidently a poor expression for Z_s, since neither $(\alpha x)^2 \cos^2 \beta x$ nor $\sin^2 \beta x$ is negligible compared with the other. In this case it is better to express the input impedance as

$$Z_s = Z_0 \frac{\cosh^2 \alpha x \cos^2 \beta x + \sinh^2 \alpha x \sin^2 \beta x}{\cosh \alpha x \sinh \alpha x + j \sin \beta x \cos \beta x}$$
$$= \frac{Z_0}{\alpha x} \frac{1}{1 + j\dfrac{\sin \beta x \cos \beta x}{\alpha x}}$$

since cosh αx = 1 and sinh $\alpha x = \alpha x$ (within one part in 10^6) and for βx *very* close to $n\pi$, $\cos^2 \beta x$ = 1 (very nearly), and $\sinh^2 \alpha x \sin^2 \beta x$ is considerably less than 10^{-6}, so is negligible compared with 1.0. Moreover for βx very close to $\beta_r x = n\pi$,

$$\cos \beta x = (-1)^n \text{ and } \sin \beta x = (-1)^n \frac{x\pi}{\lambda}\left(\frac{f}{f_r} - \frac{f_r}{f}\right)$$

So

$$Z_s = \frac{Z_0}{\alpha x} \frac{1}{1 + j\dfrac{\pi}{\alpha\lambda}\left(\dfrac{f}{f_r} - \dfrac{f_r}{f}\right)} = \frac{2Z_0^2}{Rx} \frac{1}{1 + j\dfrac{2\pi Z_0}{R\lambda}\left(\dfrac{f}{f_r} - \dfrac{f_r}{f}\right)} \tag{6}$$

where f_r is the frequency which would make the line *exactly* a multiple of a half wave length long, and f is the frequency under consideration, differing only slightly from f_r, as would be the case if the line were used for frequency control. An open-circuited line very nearly any multiple of a half wave length long evidently acts as a *parallel* resonant circuit, with a Z_s at resonance = $2Z_0^2/Rx$ and a $Q_r = 2\pi Z_0/R\lambda$.

Similarly when the open-circuited line is very nearly any *odd* multiple of a quarter wave length long, equation 2 may be readily transformed to

$$Z_s = \frac{Rx}{2}\left[1 + j\frac{2\pi Z_0}{R\lambda}\left(\frac{f}{f_r} - \frac{f_r}{f}\right)\right] \tag{7}$$

Thus an open-circuited line very nearly any odd multiple of a quarter wave length long acts exactly as a *series* resonant circuit, with a Q_r of exactly the same value as for equation 6.

Equation 6 holds not only for an open-circuited line very nearly any multiple of a half wave length long, but

also for a short-circuited line very nearly any odd multiple of a quarter wave length long. Similarly equation 7 holds not only for an open-circuited line very nearly any odd multiple of a quarter wave length long, but also for a short-circuited line very nearly any multiple of a half wave length long.

Transmission Line Constants

At commercial power frequencies with wide spacing between wires, for a parallel-wire line

$$L = \left(\mu + 4 \ln \frac{D}{r}\right) 10^{-9} \text{ henrys per centimeter length of 2-wire line}$$

$$C = \frac{1}{\left(4 \ln \frac{D}{r}\right) 9 \times 10^{11}} \text{ farads per centimeter line to line}$$

$$R = R_{d-c} = \frac{2\rho 10^{-9}}{\pi r^2}$$ ohms per centimeter length of 2-wire line, where r is wire radius and ρ (rho) is resistivity (1,724 for copper of 100 per cent conductivity and slightly larger for commercial copper)

To take account of the proximity effect if the wires are close together and of skin effect at high radio frequencies, these equations are changed to

$$L = \left\{\sqrt{\frac{2\rho}{\pi r^2 \omega \left[1 - \left(\frac{2r}{D}\right)^2\right]}} + 4 \ln \left[\frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right]\right\} 10^{-9}$$

henrys per centimeter length of 2-wire line, assuming that wire is not of magnetic material

$$C = \frac{1}{\left\{4 \ln \left[\frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right]\right\} 9 \times 10^{11}}$$ farads per centimeter, line to line

$$R' = \frac{\sqrt{2\rho f}\, 10^{-9}}{r \sqrt{1 - \left(\frac{2r}{D}\right)^2}}$$ ohms per centimeter length of 2-wire line, *excluding effect of radiation resistance*

For a copper line,

$$R' = \frac{84\sqrt{f}\, 10^{-9}}{r \sqrt{1 - \left(\frac{2r}{D}\right)^2}} = \frac{0.01455}{\sqrt{\lambda} r \sqrt{1 - \left(\frac{2r}{D}\right)^2}} \quad (8)$$

$$R = R' + \frac{2 R_{\text{rad}}}{x(1 \pm S)} \quad (9)$$

where R_{rad} is radiation resistance of the line, a function of frequency, line length, and line termination. S is discussed in detail later. It equals zero for a line any multiple of a quarter or half wave length long.

The first term in the equation for L is negligible for very high frequencies, so the equation for inductance may be written

$$L = \left\{4 \ln \left[\frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right]\right\} 10^{-9}$$ (Accurate within 1 part in 1,200 at 300,000,000 cycles)

Then

$$Z_0 = \sqrt{Z/Y} = \sqrt{L/C} = 120 \ln \left[\frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right]$$ ohms for a *parallel-wire* line (10)

For a *concentric* line at high radio frequencies

$$L = (2 \ln b/a)\, 10^{-9}$$ henrys per centimeter length of line (both conductors)

$$C = \frac{1}{(2 \ln b/a)\, 9 \times 10^{11}}$$ farads per centimeter length of line (between conductors, for air dielectric)

$$R' = 42\sqrt{f}\, 10^{-9} \left(\frac{1}{a} + \frac{1}{b}\right) = \frac{0.007275}{b\sqrt{\lambda}} \left(\frac{b}{a} + 1\right)$$ ohms per centimeter of line (11)

$$R = R' + \frac{2 R_{\text{rad}}}{x(1 \pm S)} \quad (12)$$

$$Z_0 = 60 \ln b/a \quad (13)$$

Radiation Resistance of Parallel-Wire Lines

The radiation resistance of a line is defined as equal to the power radiated in watts divided by the square of the current in amperes at a point on the line where the current has a maximum value. For an open-circuited line a quarter wave length long, such a maximum current point or current loop is at the sending end; for a short-circuited quarter-wave line it is found at the receiving end. In general current loops are found at all odd quarter-wave points, measured from the open end, on open-circuited lines; they are found at all half-wave points, measured from the shorted end, on short-circuited lines. A line terminated in its characteristic impedance of course has no standing waves, so the current has the same effective value at all points (neglecting the very small loss along the line). Therefore R_{rad} for a line terminated in its characteristic impedance is simply the power radiated divided by the square of the current.

The following equations, derived by the author, have been used in computing the data from which the curves for F, G, and H in figure 3 were plotted.

$$R_{\text{rad}} = 120 \left(\frac{\pi D}{\lambda}\right)^2 \left[\frac{1}{3} - \frac{2}{Y^2} + \left(\frac{1}{3} + \frac{1}{Y^2}\right) \sin^2 Y + \frac{1}{Y^3} \sin 2Y\right] = \left(\frac{\pi D}{\lambda}\right)^2 F \quad (14)$$

for a short-circuited line. This does not include the radiation resistance of the shorting bar, which alone equals $80(\pi D/\lambda)^2$. Total radiation resistance of a shorted line if a shorting bar is used, is $(\pi D/\lambda)^2(80 + F)$.

We have for convenience written Y for βx in all of the radiation resistance formulas. For an open-circuited line the equation becomes

$$R_{\text{rad}} = 120 \left(\frac{\pi D}{\lambda}\right)^2 \left[1 - \left(\frac{1}{3} + \frac{1}{Y^2}\right) \sin^2 Y\right] = \left(\frac{\pi D}{\lambda}\right)^2 G \quad (15)$$

For a line terminated in its characteristic impedance the equation becomes

$$R_{\text{rad}} = 120 \left(\frac{\pi D}{\lambda}\right)^2 \left[\frac{4}{3} - \frac{2}{Y^2} + \frac{\sin 2Y}{Y^3}\right] = \left(\frac{\pi D}{\lambda}\right)^2 H \quad (16)$$

Note that R_{rad} for the line terminated in its characteristic impedance equals the sum of R_{rad} for open circuit and R_{rad} for short circuit. (The derivation of these equations

and also those for the radiation resistance of concentric lines is contained in a paper by the author, entitled "Radiation Resistance of Parallel-Wire and Concentric Lines," accepted for presentation at the IRE convention to be held at Spokane, Wash., this fall. It is hoped that it will appear in an early issue of the *Proceedings* of the Institute of Radio Engineers.)

Radiation Resistance for Concentric Lines

For short circuit

$$R_{\text{rad}} = 120\frac{\pi^4}{\lambda^4}\left[b^2 - a^2\right]^2\left[\frac{1}{15} + \frac{1}{Y^2} + \left(\frac{2}{15} + \frac{9}{Y^4}\right)\sin^2 Y - \frac{12}{Y^4} - \left(\frac{1}{Y^3} - \frac{6}{Y^5}\right)\sin 2Y\right] \quad (17)$$

$$= \frac{\pi^4}{\lambda^4}(b^2 - a^2)^2 J$$

Note that this is the total radiation resistance for this case, since the shorting disk for a concentric line does not radiate.

For open circuit

$$R_{\text{rad}} = 120\frac{\pi^4}{\lambda^4}(b^2 - a^2)^2\left[\frac{1}{3} + \frac{1}{Y^2} - \left(\frac{2}{15} + \frac{3}{Y^4}\right)\sin^2 Y + \frac{\sin 2Y}{Y^3}\right] = \frac{\pi^4}{\lambda^4}(b^2 - a^2)^2 K \quad (18)$$

As in the case of the parallel-wire line, so also for concentric lines the radiation resistance for the line terminated in its characteristic impedance is the sum of the radiation resistance of the open-circuited and short-circuited lines. It may be expressed

$$R_{\text{rad}}\ (\text{for } Z_0 \text{ termination}) = \frac{\pi^4}{\lambda^4}(b^2 - a^2)^2 M \quad (19)$$

Curves for J, K, and M versus x are plotted in figure 4. A slight correction factor, depending on the values of b/λ and a/λ, and very slightly on line length, has been neglected in these formulas. For optimum values of b and a, the correction factor is less than 1 per cent. It has, however, been taken into account in computing and plotting the values of J, K, and M.

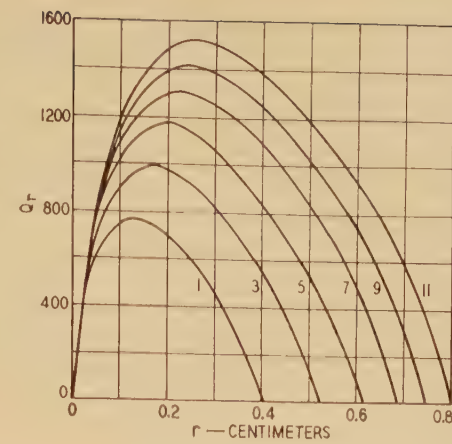
Total Resistance of Line at High Radio Frequencies

The power lost in a line evidently equals the sum of the I^2R loss and the power radiated (for leakage loss negligible, as is practically always justified in a radio-frequency line). For a line with standing waves, $I = I_0 \cos \beta s$ if the line is shorted, and $I = I_0 \sin \beta s$ if the line is open-circuited, s being distance in centimeters measured from the receiving end and I_0 being the root-mean-square current at a current loop. Then for a shorted line

$$\text{power} = I_0^2 R_{\text{rad (shorted)}} + R'\int_0^x I_0^2\cos^2\beta s\, ds = I_0^2\,\frac{x(1+S)}{2}\left[R' + \frac{2\,R_{\text{rad(shorted)}}}{x(1+S)}\right]$$

Figure 7. Parallel line, short circuit

Q_r versus r
λ = 100 centimeters
D = D_{opt}
Curve numbers refer to number of quarter wave lengths



where $S = (\sin 2\beta x)/2\beta x$. See figure 5 for a curve of S versus βx. Therefore the equivalent resistance per centimeter length for a short-circuited line is

$$R = R' + \frac{2R_{\text{rad (shorted)}}}{x(1+S)}$$

For an open-circuited line the equivalent resistance per centimeter length comes out

$$R = R' + \frac{2R_{\text{rad (open)}}}{x(1-S)}$$

For x any multiple of a quarter or half wave length, sine $2\beta x = 0$, so $S = 0$. So for both open and shorted lines at all multiples of a quarter or half wave length from the receiving end, $R = R' + 2R_{\text{rad}}/x$, the appropriate R_{rad} being used in each case. For a line terminated in its characteristic impedance, $R = R' + R_{\text{rad}}/x$.

Design of Resonant Parallel-Wire Lines for Maximum Selectivity (Maximum Q)

Equations 6 and 7 show that the Q for lines at or very near their resonant frequencies is $Q_r = 2\pi Z_0/R\lambda$. Putting into this equation the values of Z_0 and R for parallel-wire lines from equations 8, 9, 10, 14, and 15 gives

$$Q_r = \frac{240\,\pi\ln\left[\dfrac{D}{2r} + \sqrt{\left(\dfrac{D}{2r}\right)^2 - 1}\right]}{\dfrac{0.01455\sqrt{\lambda}}{r\sqrt{1 - \left(\dfrac{2r}{D}\right)^2}} + \dfrac{2\lambda}{x}\left(\dfrac{\pi D}{\lambda}\right)^2\left(\dfrac{80+F}{1+S}\ \text{or}\ \dfrac{G}{1-S}\right)}$$

Use $(80 + F)/(1 + S)$ for shorted line, and $G/(1 - S)$ for an open line.

This expression has its maximum value when

$$\frac{0.01455\sqrt{\lambda}}{r\sqrt{1 - \left(\dfrac{2r}{D}\right)^2}} = \frac{4\lambda}{x}\left(\frac{\pi D}{\lambda}\right)^2\left(\frac{80+F}{1+S}\ \text{or}\ \frac{G}{1-S}\right) \quad (20)$$

and

$$\ln\left[\frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right] = \frac{1.5\sqrt{1 - \left(\dfrac{2r}{D}\right)^2}}{1 - 2\left(\dfrac{2r}{D}\right)^2} \quad (21)$$

From 21 value of D/r to give maximum Q is

$$(D/r)_{opt} = 6.186 \tag{22}$$

Placing this value into 20 and solving for D gives

$$D_{opt} = \frac{0.134\ \lambda^{5/6}}{\sqrt[3]{\frac{\lambda}{x}\left(\frac{80+F}{1+S} \text{ or } \frac{G}{1-S}\right)}} \tag{23}$$

This expression for optimum D holds for both optimum Q_r and Q_x. For any value of x/λ, the appropriate value of F or G may be taken from curves of figures 3 and the value of S from figure 5. For instance, for a quarter-wave short-circuited line, $80 + F = 111.37$, $S = 0$, so $D_{opt} = 0.0172\ \lambda^{5/6}$.

Putting the optimum value of D into the expression for Q_r gives

$$Q_{r_{opt}} = \frac{1270\ \lambda^{1/3}}{\sqrt[3]{\frac{\lambda}{x}\left(\frac{80+F}{1+S} \text{ or } \frac{G}{1-S}\right)}} = \frac{9480}{\sqrt{\lambda}} D_{opt} \tag{24}$$

For a shorted quarter-wave parallel-wire line,

$$Q_{r_{opt}} = 166\ \lambda^{1/3} \tag{25}$$

For an open-circuited half-wave parallel-wire line,

$$Q_{r_{opt}} = 162\ \lambda^{1/3} \tag{26}$$

Since for the shorted quarter-wave line, 71.8 per cent of the radiation resistance is due to the shorting bar, the Q_r may be substantially increased (by almost 50 per cent) if the wires are brought together gradually, thus eliminating the necessity for a shorting bar. Note, however, that this also changes slightly the value of Z_0 to be used in the equation for Q_r and increases by 50 per cent the optimum D to be used.

Note that the expression for $Q_{r_{opt}}$ which we have given holds accurately only for lines close to resonant lengths (any multiple of a quarter or half wave length), the only lengths for which Q_r is of any importance. However, from this expression for Q_r, the value of Q_x for a line of any length may be accurately determined. $Q_{x_{opt}} = Q_{r_{opt}}$ $(\sin 2\beta x)/\beta x$ for both parallel-wire and concentric lines. Also Q_x for any frequency may be easily computed from the curves of figures 1 and 2.

Design of Resonant Concentric Lines for Maximum Selectivity

$$Q_r = \frac{2\pi Z_0}{R\lambda} = \frac{120\pi \ln b/a}{R'\lambda + \frac{2\lambda}{x}\frac{R_{rad}}{1 \pm S}}$$

$$= \frac{120\pi \ln b/a}{\frac{0.007275\sqrt{\lambda}}{b}\left(\frac{b}{a}+1\right) + \frac{2\lambda}{x}\frac{\pi^4}{\lambda^4}(b^2-a^2)^2\left(\frac{J}{1+S} \text{ or } \frac{K}{1-S}\right)} \tag{27}$$

Solving for optimum b/a and optimum b gives

$$b/a_{opt} = 4.22 \tag{28}$$

$$b_{opt} = \frac{0.14051\ \lambda^{0.9}}{\sqrt[5]{\frac{\lambda}{x}\left(\frac{J}{1+S} \text{ or } \frac{K}{1-S}\right)}} \tag{29}$$

Use $J/1 + S$ for short circuit, use $K/1 - S$ for open circuit, obtaining values of J and K from curves of figure 4.

Putting these values into the expression for Q_r gives

$$Q_{r_{opt}} = \frac{120\ \pi \ln 4.22}{1.25\ R'\lambda} = \frac{1{,}607\ \lambda^{0.4}}{\sqrt[5]{\frac{\lambda}{x}\left(\frac{J}{1+S} \text{ or } \frac{K}{1-S}\right)}}$$

$$= \frac{11{,}420}{\sqrt{\lambda}} b_{opt} \tag{30}$$

For a shorted quarter-wave concentric line, $J = 13.37$ and $S = 0$, so

$$b_{opt} = 0.0634\ \lambda^{0.9} \tag{31}$$

$$Q_{r_{opt}} = 725\ \lambda^{0.4} \tag{32}$$

For a half-wave concentric line shorted at both ends and fed at any intermediate point, $K = 5.43$ and $S = 0$, so

$$b_{opt} = 0.0873\ \lambda^{0.9} \tag{33}$$

$$Q_{r_{opt}} = 997\ \lambda^{0.4} \tag{34}$$

$Q_{r_{opt}}$ and b_{opt} are plotted as functions of wave length in figure 6. The $Q_{r_{opt}}$ could be increased by using a longer line shorted at both ends. For instance $Q_{r_{opt}} = 1{,}310$ $\lambda^{0.4}$ for $x = 3\ \lambda$. For a high Q_r always use a concentric line, some multiple of a half wave length long, shorted at both ends and fed at the particular intermediate point which gives the desired input impedance.

Curves in figures 9 and 10 show how Q_r decreases when a is varied, in one case holding b constant, in the other case holding the ratio b/a constant. Figures 7 and 8 show the corresponding curves for parallel-wire lines.

Design of Parallel-Wire Lines for Maximum Input Impedance

Equation 6 shows that any open-circuited line some multiple of a half wave length long, and also any short-circuited line some odd multiple of a quarter wave length long, has an input impedance

$$Z_{s_r} = \frac{2\ Z_0^2}{Rx} \quad \text{(True for both parallel-wire and concentric lines)}$$

Using the values of Z_0 and R from equations 8, 9, 10, 14, and 15 gives

$$Z_{s_r} = \frac{28{,}800 \ln^2\left[\frac{D}{r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right]}{\frac{0.01455\ x}{\sqrt{\lambda}\, r\sqrt{1-\left(\frac{2r}{D}\right)^2}} + 2\left(\frac{\pi D}{\lambda}\right)^2((80+F) \text{ or } G)} \tag{35}$$

Differentiating 35 with respect to D, and also with respect to r, and solving the resulting equations simultaneously, shows that 35 takes a maximum value when

$$D/r = 20.96 \tag{36}$$

and

$$D = \frac{0.198\ \lambda^{5/6}}{\sqrt[3]{\frac{\lambda}{x}((80+F) \text{ or } G)}} \tag{37}$$

When these values are used,

$$Z_{s_{\text{opt}}} = \frac{114{,}600\ \lambda^{1/3}}{\dfrac{x}{\lambda}\sqrt[3]{\dfrac{\lambda}{x}}\,((80 + F)\text{ or }G)} \tag{38}$$

This value is evidently a maximum for the smallest parallel resonant value of x/λ, which is $^1/_4$ for the shorted line and $^1/_2$ for the open-circuited line.

For the quarter-wave shorted parallel-wire line $F = 31.37$, so

$$D_{\text{opt}} = 0.0259\ \lambda^{5/6} \quad \text{and } Z_{s_{\text{opt}}} = 60{,}150\ \lambda^{1/3} \tag{39}$$

For the half-wave open-circuited line, $G = 120$, so

$$D_{\text{opt}} = 0.0318\ \lambda^{5/6} \quad \text{and} \quad Z_{s_{\text{opt}}} = 36{,}900\ \lambda^{1/3} \tag{40}$$

Evidently to obtain the highest possible impedance the quarter-wave line should be drawn together gradually at the shorted end, so as to eliminate the necessity for a shorting bar. In the case z_0 will be decreased somewhat, which tends to decrease the numerator of 39. However, the denominator is decreased so much more that the value of $Z_{s_{\text{opt}}}$ is increased approximately 33 per cent, giving

$$Z_{s_{\text{opt}}} \cong 80{,}000\ \lambda^{1/3} \tag{41}$$

For this case

$$D_{\text{opt}} = 0.0389\ \lambda^{5/6} \tag{42}$$

and $(D/r)_{\text{opt}}$ remains 20.96.

Evidently high impedances may be obtained in this way, for instance 371,000 ohms at $\lambda = 100$ centimeters ($f = 300{,}000{,}000$ cycles), and 800,000 ohms at $\lambda = 1{,}000$ centimeters.

Design of Concentric Lines for Maximum Impedance

From equations 11, 12, 13, 17, and 18

$$Z_{s_r} = \frac{2Z_0^2}{Rx} = \frac{7{,}200 \ln^2 b/a}{\dfrac{0.007275}{\sqrt{\lambda}}\dfrac{x}{b}\left(\dfrac{b}{a}+1\right) + 2\dfrac{\pi^4}{\lambda^4}(b^2 - a^2)^2(J\text{ or }K)}$$

$$= \frac{7{,}200 \ln^2 b/a}{\dfrac{A}{b}\left(\dfrac{b}{a}+1\right) + B\,(b^2 - a^2)^2} \tag{43}$$

This is a maximum when

$$\frac{A}{b}\left(\frac{b}{a}+1\right) = 4\,B\,(b^2 - a^2)^2 \tag{44}$$

and

$$\ln b/a = \frac{2.5[(b/a)^2 - 1]}{(b/a)^2 - (b/a) + 1} \tag{45}$$

Solving 45 gives

$$(b/a)_{\text{opt}} = 14.3 \tag{46}$$

Putting this value into 44 gives

$$b_{\text{opt}} = \frac{0.1705\ \lambda^{0.9}}{\sqrt[5]{\dfrac{\lambda}{x}\,(J\text{ or }K)}} \tag{47}$$

and

$$Z_{s_{r_{\text{opt}}}} = \frac{62{,}600\ \lambda^{0.4}}{\dfrac{x}{\lambda}\sqrt[5]{\dfrac{\lambda}{x}\,(J\text{ or }K)}} \tag{48}$$

For a shorted quarter-wave line, $J = 13.37$, so

$$b_{\text{opt}} = 0.077\ \lambda^{0.9} \tag{49}$$

$$Z_{s_{r_{\text{opt}}}} = 113{,}000\ \lambda^{0.4} \tag{50}$$

For a half-wave line shorted at both ends and fed at an intermediate point on the line, $K = 5.43$, so

$$b_{\text{opt}} = 0.106\ \lambda^{0.9} \tag{51}$$

$$Z_{s_{r_{\text{opt}}}} = 77{,}750\ \lambda^{0.4} \tag{52}$$

Evidently the quarter-wave shorted concentric line should be used if an enormous impedance (a pure resistance) is desired. Such a line represents an impedance of 713,000 ohms at a wave length of 100 centimeters, an impedance of 1,793,000 ohms at a wave length of 1,000 centimeters, and correspondingly higher impedances for longer wave lengths (lower frequencies).

Design for Low Loss When Line Is Terminated in Its Characteristic Impedance

For both the transmission and reception of high-radio-frequency waves, either parallel-wire or concentric lines may be used to connect the antenna to the transmitter or receiver. In airplanes and in police cars, equipped for 2-way ultrashort-wave radio communication, such transmission lines may be only a fraction of a wave length long. At commercial radio transmitting or receiving stations the transmission lines may be many wave lengths long. In any case it is important to terminate the line at both ends in an impedance equal in magnitude and phase to the characteristic impedance of the line, so as to prevent the formation of standing waves on the line. When a line is so terminated, the transmission line equations reduce to

$$E_s = E_r\,\epsilon^{px} = E_r\,\epsilon^{\alpha x}.\epsilon^{j\beta x}$$

$$I_s = I_r\epsilon^{px} = I_r\epsilon^{\alpha x}.\epsilon^{j\beta x}$$

$$Z_s = Z_r = Z_0$$

$$P_r = P_s\epsilon^{-2\alpha x}$$

(P_r and P_s stand for power at receiving and sending ends of the line, respectively)

and the power loss expressed in decibels is

$$N_{db} = 8.686\,(\alpha x) = 8.686\frac{Rx}{2Z_0} = 8.686\,\frac{\pi x}{\lambda}\,\frac{R\lambda}{2\pi Z_0} = \frac{8.686\pi x}{\lambda Q_r}$$

the value of Q_r being equal to $2\pi Z_0/R\lambda$, just as for open or short-circuited lines. Evidently the loss is a minimum when Q_r is a maximum.

For parallel-wire lines, from equation 23, noting that $H/2$ is to be substituted for $(80 + F/1 + S)$ or $(G/1 - S)$,

$$D_{\text{opt}} = \frac{0.134\ \lambda^{5/6}}{\sqrt[3]{\dfrac{\lambda}{x}\,\dfrac{H}{2}}} \tag{53}$$

This was a good form in which to leave the equation in the case of open or short-circuited lines, in which x was al-

most invariably either $\lambda/4$ or $\lambda/2$; however, it is better in the case of lines terminated in their characteristic impedance, where x is ordinarily not an exact multiple of a quarter or half wave length, to express D_{opt} as

$$D_{opt} = 0.169\ \lambda^{0.5} \sqrt[3]{\frac{x}{H}} \tag{54}$$

$(D/r)_{opt} = 6.186$, as was found also for $Q_{r\,opt}$.

Loss when optimum design is used is (N_{db} stands for number of decibels loss)

$$N_{db} = 0.01705 \frac{x}{\lambda} \sqrt[3]{\frac{H}{x}} \tag{55}$$

Example: For λ = 100 centimeters and $x = 4\ \lambda$

D_{opt} = 2.29 centimeters
r_{opt} = 0.37 centimeter
N_{db} = 0.0502 decibel

Of this loss, exactly one third represents power radiated from the line. To see how much the loss is increased if optimum design is not used, refer to curves in figures 7 and 8. Although this line is 4 wave lengths long, whereas the longest line for which curves are drawn is 11 quarter wave lengths long, note that practically the same relations hold for all the curves. Therefore the error involved in using curve 11 in either figure 7 or figure 8 is negligible. Since the loss is inversely proportional to Q_r, evidently

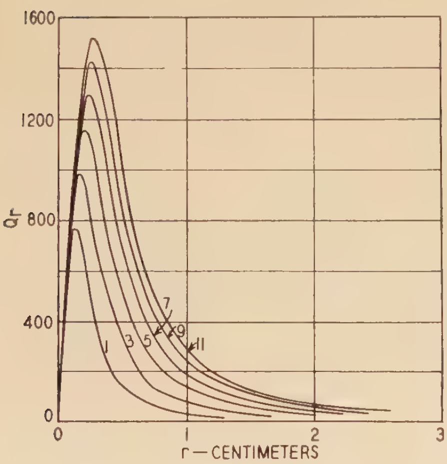


Figure 8. Parallel line, short circuit

λ = 100 centimeters
Q_r versus r
$D/r = D/r_{optimum}$
Curve numbers refer to number of quarter wave lengths

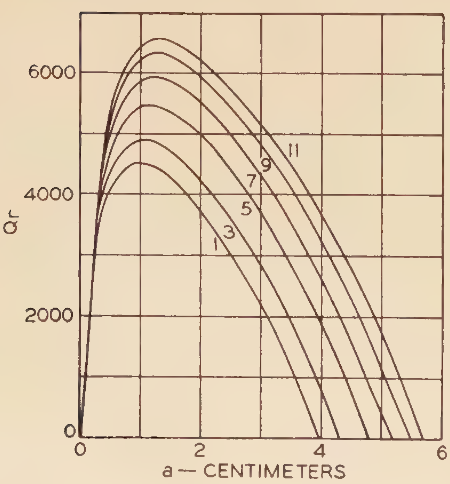


Figure 9. Concentric lines, shorted

λ = 100 centimeters
$b = b_{opt}$
Q_r versus a

Figure 10. Concentric line, short circuit

λ = 100 centimeters
Q_r versus a
$b/a = (b/a)_{opt}$

the curves showing Q_r can be used to compute the variation in loss as the design is changed from the optimum one.

Example: How much would the loss be increased if r were made $^1/_4$ of its optimum value, holding $D = D_{opt}$ = 2.29 as just computed? Using curve 11 in figure 7, we see that $Q_{r\,opt}$ = 1,530 at r = 0.255 centimeter. At r = 0.255/4 = 0.06375, Q_r = 955. But 1,530/955 = 1.605. So the loss has been increased by 60.5 per cent.

Example: How much would the loss be increased if D/r remained $(D/r)_{opt}$, but both D and r were made 4 times their optimum values? In this case use curve 11 of figure 8. Q_r = 1,530 at r = 0.255 centimeter. At $r = 4 \times 0.255$ = 1.02 centimeters, Q_r = 280. Since 1,530/280 = 5.46, evidently the loss has been increased from 0.0502 decibel (the loss for optimum design) to 5.46 $\times$ 0.0502 = 0.274 decibel. In this case it is interesting to note that 97 per cent of the total loss is due to radiation from the line, whereas for the optimum design only one third the loss was due to radiation.

For a concentric line, from equation 29, substituting $M/2$ for $(J/1 + S)$ or $(K/1 - S)$,

$$b_{opt} = \frac{0.14051\ \lambda^{0.9}}{\sqrt[5]{\frac{\lambda}{x}\ \frac{M}{2}}} = \frac{0.1615\ \lambda^{0.7}}{\sqrt[5]{\frac{M}{x}}} \tag{56}$$

$\left(\frac{b}{a}\right)_{opt}$ = 4.22 (same as for maximum Q_r), and N_{db} =

$$0.0148\ \frac{x}{\lambda} \sqrt[5]{\frac{M}{x\lambda}} \tag{57}$$

For concentric lines, the loss due to radiation is one fifth of the total loss, if the line is designed for maximum Q_r (or minimum loss). From the curves in figure 9 and figure 10 one may readily determine how much the loss is increased if the optimum design is not followed. Since for concentric lines the total loss is so small, it will often be advantageous to build the line with considerably less than the optimum dimensions, in the interest of over-all economy.

It is of interest to note that a concentric line, terminated

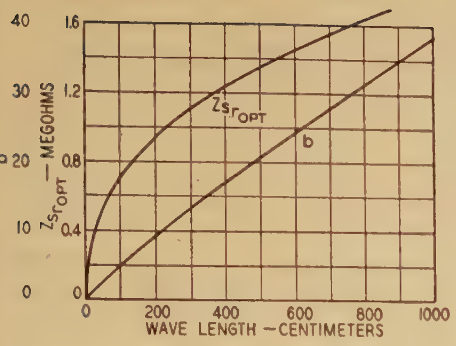


Figure 11. Optimum Z_{sr} and b versus λ for quarter-wave shorted concentric line

in its characteristic impedance, has a maximum value of radiation resistance, and therefore radiates maximum power, when it is 0.6 of a wave length long. Note that $M = 59.5$ for this value of x, decreasing gradually as the line length increases until for all lengths above about 4 wave lengths its value is about 47.5. For parallel-wire lines also, as shown by the curve for H in figure 3, if the line is at least 3 or 4 wave lengths long, further increase in length has no effect on the radiation resistance. So a line radiates the same amount of power whether it is 3 or 4 wave lengths long or 3,000 or 4,000 wave lengths long, if it is terminated in its characteristic impedance.

Note also that the radiation from an open-circuited concentric line cannot be decreased by partially closing the end. This follows immediately from the fact that the shorting disk used to short a shorted concentric line does not radiate. Since such a disk does not radiate power itself, it cannot prevent the radiation of power through it from the current in the line. Moreover, a line supposed to be open-circuited should never have the end partially closed with metal, since the presence of such metal greatly increases the capacity at the end, and in effect terminates the line with a low value of capacity reactance, instead of the desired open circuit.

References

1. Transoceanic Telephone Service—Short-Wave Equipment, A. A. Oswald. *Bell Technical Journal*, April 1930, bottom of page 277.

2. Phase Synchronization in Directive Antenna Arrays With Particular Application to the Radio Range Beacon, F. G. Kear. Bureau of Standards *Journal of Research*, July 1933, page 129.

3. A New High Efficiency Power Amplifier, W. H. Doherty. IRE *Proceedings*, September 1936, page 1172.

4. Resonant Lines in Radio Circuits, F. E. Terman. Electrical Engineering (AIEE Transactions), July 1934.

5. Frequency Control by Low Power Factor Line Circuits, C. W. Hansell and P. S. Carter. IRE *Proceedings*, April 1936.

6. A Unicontrol Radio Receiver for Ultrahigh Frequencies Using Concentric Lines as Interstage Couplers, F. W. Dunmore. IRE *Proceedings*, June 1936.

7. Transmission Lines for Short-Wave Radio Systems, E. J. Sterba and C. B. Feldman. IRE *Proceedings*, July 1932.

8. Radiation Resistance of Concentric Conductor Transmission Lines, Robert Whitmer. IRE *Proceedings*, September 1933.

Radiotelephone Noise Reduction

(*Continued from page 974*)

such a control terminal. Speech entering the terminal from the left goes through the upper branch of the circuit, with volume regulating means and privacy apparatus, to the radio transmitter. Speech received from the distant terminal enters at the lower right from the radio receiver and proceeds through the privacy apparatus, the noise reducer, receiving regulating network and amplifier to the 2-wire line. Outgoing speech operates the transmitting path and disables the receiving path. Incoming speech operates the receiving amplifier detector, which disables the transmitting amplifier detector, thus preventing singing and reradiation of received waves.

Without the noise reducer the receiving relay may be operated by noise in the receiving path and such operation to an excessive extent will interfere with outgoing speech. To avoid this effect, it is customary to reduce its sensitivity so that noise may not operate it. This results in the weaker speech parts also failing to operate the receiving relay. This weak speech and noise returned to the transmitting path through the land-line connection may be strong enough to operate the transmitting relays and thus cut off incoming speech. This is avoided by reducing the volume to the land line. Therefore, any device which reduces noise in the receiving path in the absence of speech effects an improvement not only in the switching operation but also in the received volume. By placing the noise reducer in the receiving path false operation is diminished and volume increases of 5 to 15 decibels are realized. The noise reducer is applied to the receiving side of the terminal beyond the privacy apparatus so that it does not introduce any distortion in the privacy portion of the circuit. It is placed ahead of the receiving amplifier detector, thereby reducing noise between words which might affect the operation of this relay apparatus.

Summary

The noise reducer, which is a voice-controlled variolosser with limited and controllable action, has been provided for use on short-wave radiotelephone circuits and has proved to be a valuable and relatively inexpensive means of securing noise reduction. Improved reception is obtained for many of the transmission conditions experienced on such circuits. This results in better intelligibility to the subscriber, greater margin in the operation of 2-way radiotelephone circuits, and a reduction of difficulties in the wire plant caused by connection to noisy radio circuits.

References

1. Speech and Hearing, H. Fletcher. D. Van Nostrand Company, 1929.

2. Effects of Phase Distortion on Telephone Quality, J. C. Steinberg. *Bell System Technical Journal*, July 1930.

3. Ship-to-Shore Radio in Puget Sound Area, E. B. Hansen. Electrical Engineering, volume 24, August 1935.

4. A Telephone System for Harbor Craft, W. K. St. Clair. *Bell Laboratories Record*, November 1932.

5. A Noise Reducer for Radiotelephone Circuits, N. C. Norman. *Bell Laboratories Record*, May 1937.

6. The Reliability of Short-Wave Radiotelephone Circuits, R. K. Potter and A. C. Peterson, Jr. *Bell System Technical Journal*, July 1934.

7. Two-Way Radiotelephone Circuit, S. B. Wright and D. Mitchell. *Bell System Technical Journal*, July 1932.

8. The Vodas, S. B. Wright. Electrical Engineering, August 1937.

The Vodas

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Introduction

THE INTERCONNECTION of ordinary telephone systems by means of long radiotelephone links presents some unique and interesting technical problems. Since radio noise is often severe as compared with that in wire lines, radio transmitter power capacity is relatively large and expensive, and it is in general economical to control the speech volumes so that the radio transmitter will be fully loaded and thus the effect of noise minimized for a given transmitter power rating. This volume control, to be fully effective, calls for voice-operated switching devices to suppress echoes and singing.

This paper describes the measures which have been developed for use at radio-wire junctions in the United States. They are based upon an arrangement called a "vodas." This word, devised to fill a need for verbal economy, is formed from the initial letters of the words "*v*oice-*o*perated *d*evice *a*nti-*s*inging"; and thus implies not only a suppressor of feedback or singing, but also automatic operation by voice waves.

The general principles and applications of the vodas have been discussed from time to time in various papers listed at the end of this text. The present paper goes somewhat more into detail regarding the transmission performance of the vodas, including a description of an improved form of circuit which discriminates between line noise and the syllabic characteristics of speech.

Historical

The 2-way problem in telephony began with the invention of the telephone itself, and was the subject of considerable pioneering activity during the latter part of the nineteenth century. The invention of the amplifier brought about new problems when applied in a repeater for 2-way operation. Even before a practical repeater had been devised, inventors visualized controlling the direction of transmission through amplifiers in a line by relays controlled from switches associated with the subscribers' instruments, an idea which is in use today on airplanes and small boats and in special circuits where this type of 2-way operation is practicable. It is also used by amateur radiotelephone operators. But for public telephone service more rapid and automatic control of 2-way conversation is preferable.

To control the direction of transmission in a manner that would meet public convenience invention progressed through the early part of the twentieth century toward devices for switching the speech paths automatically by voice waves. During this period, long-distance radiotelephony was first demonstrated to be practical on a one-way basis.

From that time until the first trans-Atlantic radiotelephone circuit was placed in service on January 7, 1927, antisinging voice-operated devices underwent a process of development aimed at meeting the requirements of 2-way radiotelephone service. The vodas was one result. Since 1927, improvements have been made in cheapening and simplifying the equipment and in making a vodas that will operate better on speech and not so frequently on noise. It has also been possible to arrange a vodas so as to permit using the same privacy apparatus for both directions of transmission, thereby saving the cost of duplicate apparatus.

The Radiotelephone Problem

The conditions encountered when joining 2-wire 2-way circuits by radio links are illustrated in figure 1 in which *a* shows a connection between 2 subscribers *W* and *E* while *b* shows the paths of direct transmission and echo when *E* talks. In addition to the talker and listener echoes which arise in such a connection, singing can occur around the closed circuit *CAFGDBC* if the amplification is great enough. Also, when the same frequency band is used to transmit in both directions, 2 cross-transmission paths *AB* and *DF* are set up, and echoes and singing can take place around the end paths *ABC* and *DFG*. Any echoes or singing are of course primarily due to reflections of energy at points of impedance irregularities in the 2-wire plant, including the subscribers' telephones themselves.

In wire circuits, simple hybrid coils and echo suppressors[2] are usually adequate to prevent such effects because the gains are not increased to provide for loading the cir-

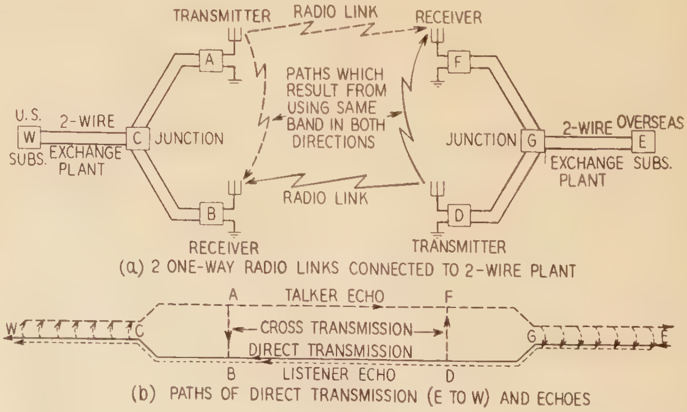

Figure 1. Echoes in a radiotelephone connection

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2. For all numbered references, see list at end of paper.

cuit with energy when speech is weak, and also because the cross-transmission paths are absent. In long radio circuits, however, singing may result from the adjustments of amplification made to load the radio transmitter in case of weak speech and thus override noise, even though separate frequency bands are used in the 2 directions. Moreover, it is desired that the users of the service have as good transmission over the entire connection including these radio links as that to which they are accustomed in their own wire telephone systems and even better transmission may be desired owing to differences in the language habits of the subscribers. Consequently, the over-all transmission efficiencies of intercontinental radio circuits are sometimes better than those of the best land lines in the areas to be interconnected.

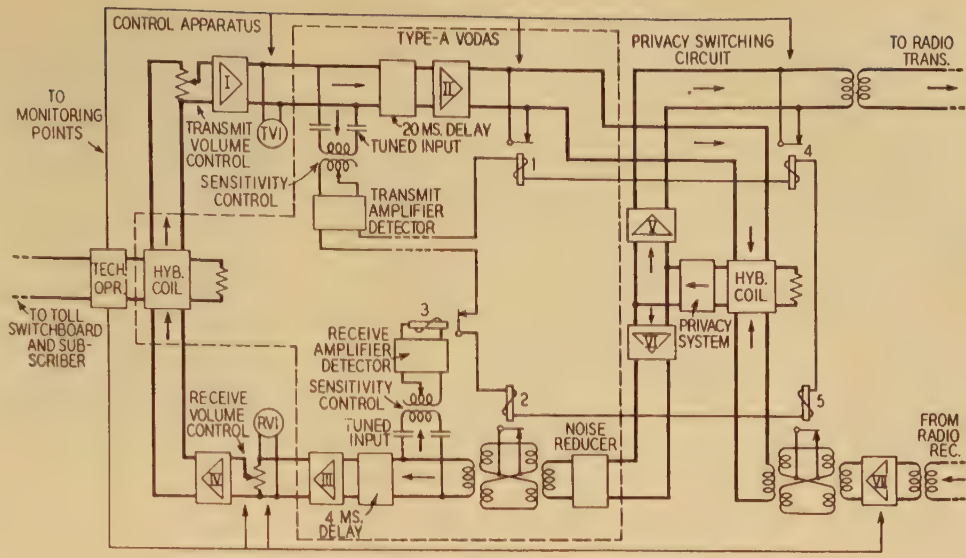


Figure 2. Schematic of type-A control terminal

Fundamentals of Vodas Operation

A voice-operated device to suppress singing effects can be designed to have 3 possible arrangements:

1. The terminal can normally be blocked in one direction and connected through in the other.

2. Both directions of transmission can normally be blocked and activated in either but not both directions by the voice waves.

3. The circuit can remain activated in the last direction of speech and blocked in the other direction.

Where there is no noise on the transmission system under consideration any of these 3 arrangements will give satisfactory operation as there is then nothing to prevent making the voice-operated devices as sensitive as may be necessary to obtain full operation on weak as well as on strong voice waves. If there is any noise on the system which tends to operate the device it is necessary to make it less sensitive to avoid false operation. A point may be reached where the sensitivity is so low that the weakest parts of speech will not cause operation, and the weak consonants will be lost. The reduction in articulation has been found to be proportional to the time occupied by these lost or "clipped" sounds.[9]

If the device is located at a point in the circuit where the signal-to-noise ratio coming from one direction is poorer than that coming from the opposite direction it is obvious that a considerable advantage will be gained by using arrangement 1, since the device may be pointed in the direction in which the normally blocked path is exposed to the better signal-to-noise ratio and the normally activated path is exposed to the poorer signal-to-noise ratio. The vodas is, of course, arranged so that the normally blocked (transmitting) side is exposed to the land lines which are usually quieter than the radio links. In the receiving side, the device can be less sensitive because there is no need for having it completely operated under control of the voice waves. All that is necessary is to have this side sensitive enough to operate in response to comparatively large voice or noise waves which might otherwise, after reflection and passage into the outbound path, result in false operation of the more sensitive side associated with this path.

In the vodas the principle of balance is used to keep the

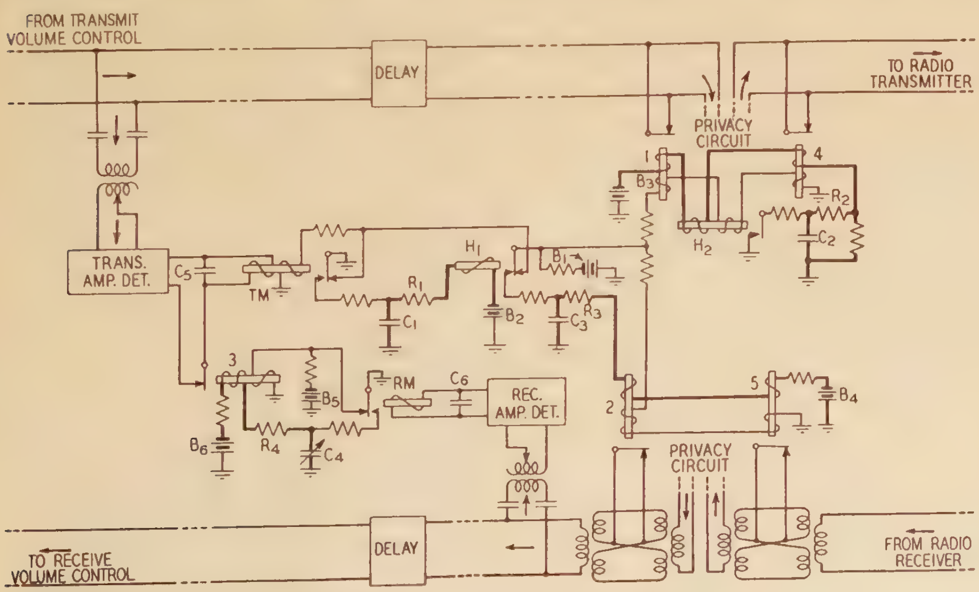


Figure 3. Vodas relay circuits

reflected currents small and thus allow the sensitivity of the normally activated device to be further reduced if necessary. Where a high degree of balance is not obtained and when noise from the radio limits the sensitivity of the receiving device it is sometimes necessary, particularly for weak outgoing volumes, to reduce the incoming volume so as to prevent echoes from operating the normally blocked transmitting side.

This echo limitation is primarily due to noise in the radio link, reflections from the 2-wire plant and weak volumes from the subscribers. It is difficult to produce any large improvement in talker volumes and balance; so it would appear that the solution of the difficulty would probably come from the direction of improving radio transmission. Some benefit has also been obtained by reducing the effect of radio noise on the vodas with special devices of which the "compandor"[17,18] and the "codan"[19,20] are examples. More recently, use has been made of a new voice-controlled device called a "noise reducer,"[21,22] which reduces the received noise between speech sounds.

Vodas Design—Type-A Control Terminal

Figure 2 shows a schematic diagram of a vodas arranged to use the same privacy device for both transmitting and receiving. The vodas apparatus together with the volume-control devices and technical operator's circuits go to make up what is called a type-*A* control terminal. This is the type used on trans-Atlantic and other long routes. Since the operation of this arrangement has been described before,[13] it will not be repeated here.

The diagram of the relay circuit in figure 3 shows how various time actions are obtained. Relays 1, 2, 4, and 5 are operated from battery B_1 when the ground contact of relay TM is opened. Thus the travel time of any relay armature is not a factor in securing fast initial operation. When the armature of relay TM reaches its left-hand contact, relay H_1 operates and delays release of the relay train even if TM is at once restored to normal. H_1 is delayed in releasing by the time required to charge condenser C_1. The final release of relays 1 and 4 is then controlled by the time constant of an auxiliary circuit involving relay H_2 and condenser C_2, while that of relays 2 and 5, which is made later so as to suppress delayed echoes, is controlled by the circuit charging C_3. On the receiving side, condenser C_4 is adjustable so as to permit the technical operator to select the shortest release time for suppressing the delayed echoes in a given land-line extension.

The vodas control terminal of the *A* type[8] used at New York consists of a line of technical operating positions

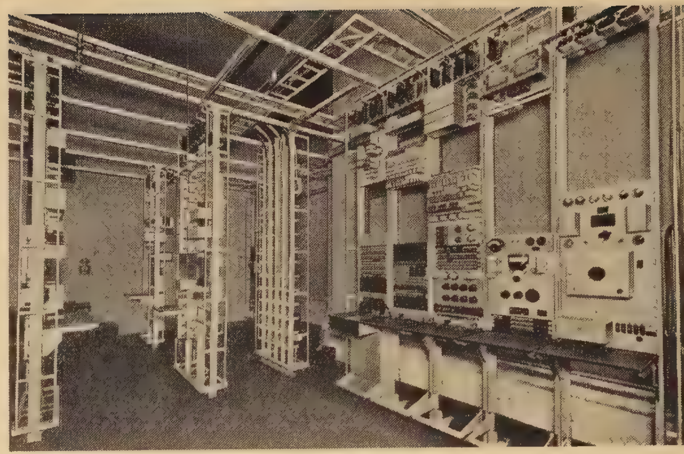


Figure 4. Type-A control terminal at San Francisco

with cross connections to other lines of equipment containing the delay units, repeaters, vodas amplifier-detectors, and privacy apparatus. Figure 4 shows an arrangement of a single terminal at San Francisco. The control bay is placed between 2 line-testing bays on the left and 2 transmission-testing bays on the right of the operating lineup. The distributing frame is in the center of the picture; and repeaters, ringers, and privacy apparatus are shown at its left. At the extreme left is the vodas bay.

Syllabic Vodas—Type-B Control Terminal

The desire for a cheaper control terminal than the type *A* led to the development of a second type, known as type *B*, in which the vodas employs the same fundamental principles. In this vodas added protection against false operation from line noise is secured by the use of a new principle in voice-operated devices, called "syllabic" operation.

It is observed that in many types of noise a large component of the long-time average power is steady. Speech, however, comes as a series of wave combinations of relatively short duration. These facts suggested a device

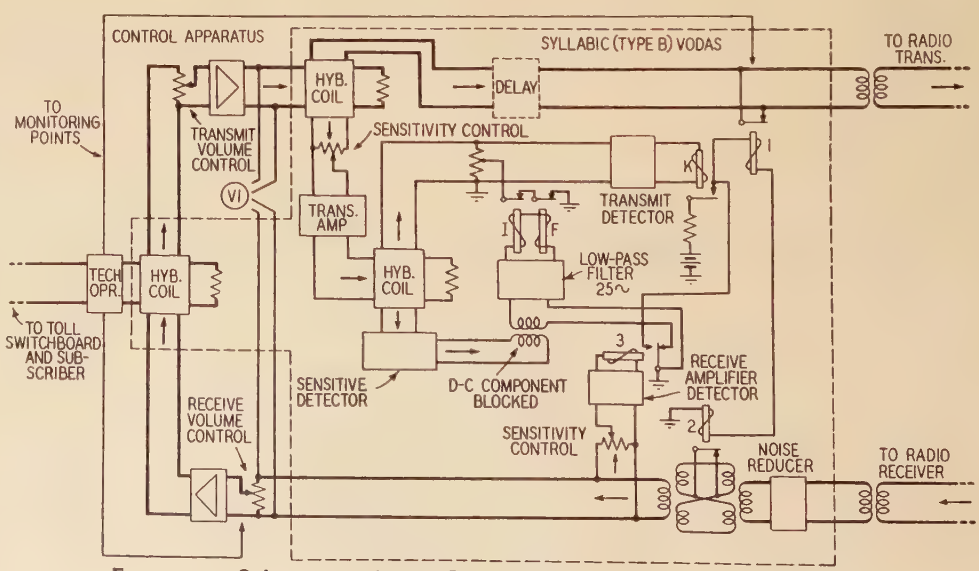


Figure 5. Schematic of type-B control terminal with syllabic vodas

which distinguishes between the rates of variation of the envelopes of the impressed waves. This is accomplished by a filter in the detector circuit which passes the intermodulated components of speech in the syllabic range, but suppresses those of line noise which are above or below this range.

Figure 5 shows a schematic diagram of the application of this device to a type-*B* control terminal. The privacy switching circuits are omitted from this drawing, as are also the circuits for delaying the release of the relays. In comparing this drawing with figure 2, it will be seen that relays 1, 2, and 3 perform the same functions, but the transmitting branch of the vodas consists of 2 portions, one a sensitive detector with a syllabic frequency filter, which on operation increases the sensitivity of the second portion.

Considering the action of figure 5 on transmitted speech, the output of the sensitive detector of the syllabic device is a complex function of the applied wave having intermodulated components in the range passed by the tuned input circuit, together with a d-c component and various low-frequency components set up by the syllabic nature of the speech. There are also various components of any noise waves which may be present including a d-c component. The first step in getting rid of the noise is to pass the detector output through a repeating coil which blocks the d-c component of both the speech and noise, but passes frequencies above about $^1/_2$ cycle per second. The resulting waves enter the low-pass filter, the output of which contains frequencies between $^1/_2$ and 25 cycles per second which "syllabic range" is between the d-c component of zero frequency and the fundamental frequency of the line noise. These syllabic-frequency currents cause momentary operations of relays *I* and *F*. Relay *I* operates when a speech wave is commencing and relay *F*, which is poled oppositely, operates while the impulse is dying out, thus sending current out of the filter in the opposite direction. Operation of either *I* or *F* effectively inserts gain ahead of the upper detector, thereby increasing the sensitivity of relay *K*, when speech is present. Even if the noise is strong enough to operate relay *K* over the upper branch when the gain is inserted, the release of relay *F* at the end of a speech sound will remove the gain and permit *K* to fall back. Thus, it is possible to work relay *K* more sensitively on weak speech than would be possible without the syllabic device.

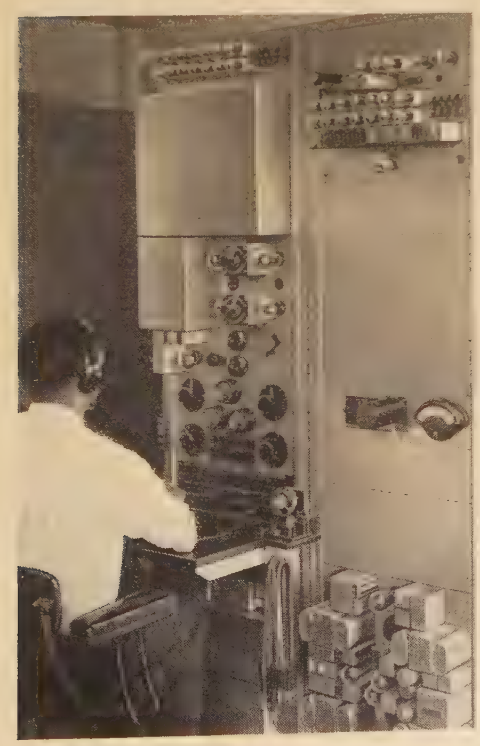
Figure 6 shows a photograph of a *B*-type terminal in ship-to-shore service at Forked River, N. J. The vodas and volume control apparatus are in the left-hand cabinet. The right-hand cabinet contains privacy apparatus, a signaling oscillator, and a vodas relay test panel.

Performance

In any system employing voice-operated devices it is necessary for the time actions to provide for to-and-fro conversation with a minimum of difficulty when the subscribers desire to reverse the direction. The electromagnetic relays used in the vodas have advantages over other types of switching arrangements which have been proposed in that they (1) operate and release at definite current values; (2) have fast operating and constant releasing times; (3) have their windings and their contacts electrically separated, thus simplifying the circuits; and (4) operate in circuits having low impedances.

The operating times of the 2 types of vodas are shown in figure 7 as a function of the strength of suddenly applied single-frequency sine waves in the voice range. These measurements were made with a capacity bridge.[5] The sensitivities of the 2 types were adjusted so that observers noted an equivalent amount of clipping. The type-*A* vodas was provided with a 20-millisecond delay circuit, the type *B* had no delay. For the type-*A* vodas, the operating time is quite small and constant just above the threshold of operation.

For weak inputs the operating time of the syllabic device is determined by relay *I* and the filter, as shown in



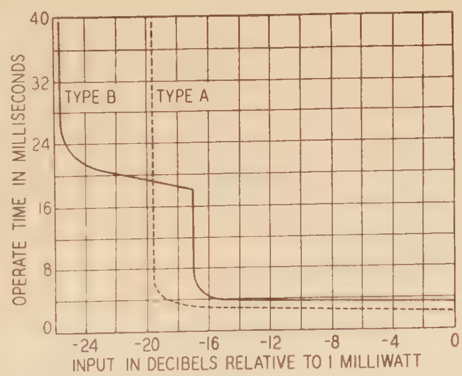
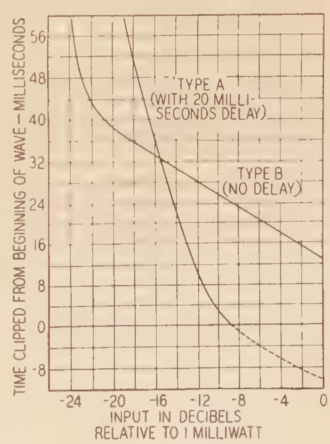


Figure 7 (above). Vodas operating times with sine waves suddenly applied

Figure 8 (right). Operation on a 5-cycle-per-second sine wave

Figure 6 (left). Technical operator at Forked River, N. J., using a type-B control terminal to establish a circuit between a steamship and a shore telephone operator



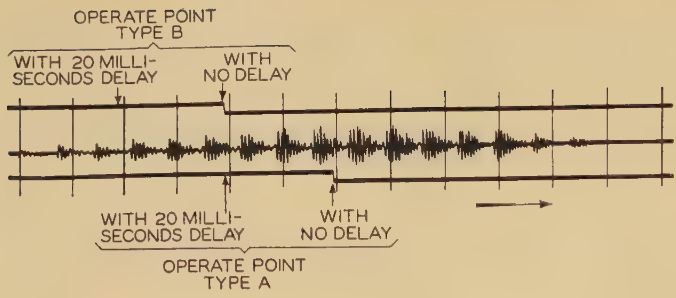


Figure 9. Oscillogram of the word "six," illustrating clipping and its reduction by a delay circuit in the transmission path

figure 7. As the suddenly-applied input is increased, a point is reached where the less sensitive detector operates relay *K*, reducing the operating time from around 20 milliseconds to values comparable with those of the type *A*.

The operation was also tested on waves formed by applying simultaneously 2 sine waves of equal amplitude but slightly different frequencies. These waves were recorded on an oscillograph together with a d-c indication of the operation of each of the vodas relays, with the sensitivities adjusted the same as for figure 7. The time from the beginning of a beat wave (null point) to the time of operation was measured from these oscillograms and plotted against various values of total applied voltages. Figure 8 shows the results for a 5-cycle-per-second difference between the 2 frequencies. Negative values of time indicate that the path was cleared before the beginning of the wave, and these occur only with the type-*A* vodas due to the delay circuit. The curves for frequency differences of less than 5 cycles per second show more clipping and greater differences between the devices, while those for greater frequency differences show less time clipped and less difference between the 2 types of vodas. In the case of weak waves it is evident that the syllabic will give less clipping because the energy of the wave does not rise to the value required to operate the type-*A* device until after the syllabic device has operated; and for very weak waves, the type *A* does not operate at all. In the case of strong waves, the type-*A* vodas is better due to its delay circuit. However, since the clipped time is greater on weak sounds than on strong ones, the 2 types give performances on speech which are judged to be equivalent.

A comparison of operation of the 2 types of vodas on a speech wave is shown in figure 9. Reading from left to right the middle trace of this oscillogram shows the wave recorded by saying the word "six" over a telephone circuit transmitting a band of frequencies from about 800 to 2,000 cycles per second, which is the range normally effective in operating the vodas. The upper trace shows the point at which the syllabic type-*B* device operated and the lower trace shows the point at which the type-*A* device operated. Since the speech wave shown was used to operate both devices, the reduction of clipping by the delay circuit in the type-*A* vodas was not recorded. However, the effect of a transmission delay of 20 milliseconds is shown by subtracting 20 milliseconds from the point at which operation occurred. This is indicated on the oscillogram for both devices. It is concluded that on this wave the syllabic device without a delay circuit would give about the same clipping as the type-*A* vodas with its delay circuit. Figure 8 indicates that the type *A* would be better for stronger speech and the type *B* would be better for weaker speech. The advantage of a delay circuit is either case is evident.

It is evident from this analysis that the reason for using delay circuits is not primarily because the relays are slow in operating. When the sensitivity is limited by noise, clipping of initial consonants can occur with infinitesimal operating times. One way of reducing the clipping is to use long releasing times so that the relays remain operated between syllables. This has the disadvantage of making it harder for the opposite talker to break in. To avoid this difficulty, the relays in the vodas are given releasing times that permit the distant speech to break in about $^1/_6$ second after a United States talker ceases to speak.

One advantage of delay circuits is to reduce the clipping of initial consonants and thus permit using short releasing times, thereby making it possible to reverse the circuit more readily. In addition, delay circuits permit using a lower relay sensitivity which has 2 advantages: First, more noise can be tolerated without causing false operation; second, more received volume can be delivered without the echoes causing false operation of the normally blocked transmitting side.

The advantage of artificial delay of various amounts has been determined using different types of normally blocked arrangements to find the relation between the delay and the sensitivity required to produce given amounts of clipping of initial sounds. The results are shown for a

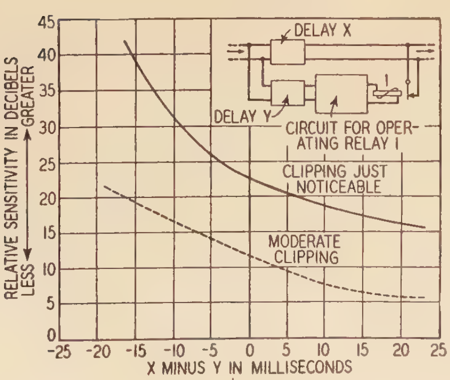
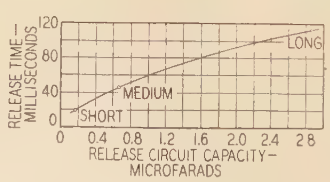


Figure 10 (left). Typical delay versus sensitivity for certain clipping effects

Figure 11 (below). Release time versus capacity



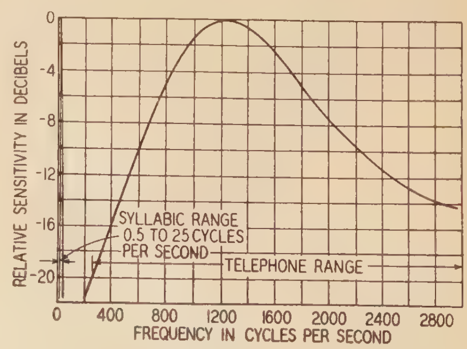


Figure 12. Sensitivity-frequency characteristics of the vodas

type-A vodas in figure 10. The curves for the syllabic device are similar. The setup was arranged so that various delays could be inserted in either the transmission circuit (delay X) or the relay circuit (delay Y). The left ends of the curves indicate that when delay Y is used, that is, when the net operating time of the relay is great, a point will be reached where no reasonable increase in sensitivity is sufficient to prevent intolerable clipping. The value of 20 milliseconds of delay X as compared to zero is equivalent to an increase of about 5 decibels in sensitivity for a given amount of noticeable clipping.

A reasonable release time is of value in preventing clipping, as it causes the relays to remain operated not only for trailing weak endings of sounds, but also when the energy is temporarily reduced by intermediate consonants which may be comparable with noise. Delayed release is also important when it is required to maintain the blocked condition while delayed echoes are being dissipated. For these echoes, the hangover or release times should be constant for various applied voltages. In the vodas, the change in release time over a wide range of inputs is less than one per cent. Adjustments are made by varying the condensers and resistances of the auxiliary circuits shown in figure 3. Typical values obtained by this method are indicated in figure 11.

The vodas amplifier-detectors have broadly tuned input circuits to exclude by frequency discrimination many of the frequencies induced by power sources and those which are unnecessary for speech operation. The sensitivity-frequency characteristic is shown on figure 12. This figure also shows the relatively narrow frequency range passed by the repeating coil and syllabic frequency filter of the type-B vodas.

Operating Attendance

To insure proper operation of a vodas a technical operator[3] is in attendance. He is provided with circuits which enable him to talk and monitor on the circuit as indicated in figures 2 and 5. His duties include adjusting the sensitivity of the receiving relays for the particular value of radio noise existing and adjusting the transmitting and receiving speech volumes by the aid of potentiometers and volume indicators. He selects the proper hangover time and co-ordinates the operation of the circuit as a whole with the distant end. At times, he may be required to increase the sensitivity of the transmitting side of the vodas in the case of talkers with poor ability to operate relays or to decrease the sensitivity when weak volumes are supplied from land lines with more than the usual amount of noise.

Summary

The vodas is used in radiotelephony to switch the voice paths rapidly to and fro, and thus prevent echoes and singing that would otherwise occur at unpredictable times. It is also used to save privacy apparatus by permitting the use of the same apparatus for both directions of transmission. The performance characteristics of the electromagnetic relays used in the vodas are very suitable in that they have small operating and constant releasing times.

Improved performance of the voice-operated relays in the presence of line noise can be secured by the use of a syllabic type of vodas which discriminates between the characteristic voltage-time envelopes of the noise and speech waves. Laboratory and field tests indicate that this device even without delay circuits, gives slightly better performance on most conditions than the original vodas with delay. When provided with a transmitting delay circuit, the syllabic device is decidedly better than the older vodas.

References

The International Bibliography on the Co-ordination of Radiotelephony and Telephony is given in the C.C.I.F. Green Book, volume I of the proceedings of the tenth plenary meeting, held at Budapest, September 1934. Below is given a chronological list of Bell system papers relating to the vodas.

1. The Limitation of the Gain of Two-Way Telephone Repeaters by Impedance Irregularities, George Crisson. *Bell Sys. Tech. Jl.*, volume 4, January 1925, pages 15–25.

2. Echo Suppressors for Long Telephone Circuits, A. B. Clark and R. C. Mathes. AIEE Journal, volume 44, June 1925, pages 618–26. *Elec. Commun.*, volume 4, July 1925, pages 40–50. AIEE Transactions, volume 44, 1925, pages 481–90.

3. The New York-London Telephone Circuit, S. B. Wright and H. C. Silent. *Bell Sys. Tech. Jl.*, volume 6, October 1927, pages 736–49.

4. Echo Elimination in Transatlantic Service, G. C. Crawford. *Bell Lab. Record*, volume 5, November 1927, pages 80–4.

5. Bridge for Measuring Small Time Intervals, J. Herman. *Bell Sys. Tech. Jl.*, volume 7, April 1928, pages 343–9.

6. Problems in Power-Line Carrier Telephony, W. B. Wolfe and J. D. Sarros. AIEE Journal, volume 47, October 1928, pages 727–31. AIEE Transactions, volume 48, 1929, pages 107–13.

7. A Carrier Telephone System for Power Lines, C. F. Boeck. *Bell Lab. Record*, volume 7, July 1929, pages 451–8.

8. Voice-Frequency Equipment for the Transatlantic Radio Telephone, J. A. Coy. *Bell Lab. Record*, volume 8, September 1929, pages 15–20.

9. Effects of Phase Distortion on Telephone Quality, J. C. Steinberg. *Bell Sys. Tech. Jl.*, volume 9, July 1930, pages 550–6.

10. Electrical Delay Circuits for Radio Telephony, R. T. Holcomb. *Bell Lab. Record*, volume 9, January 1931, pages 229–32.

11. Acoustic Delay Circuits, W. P. Mason. *Bell Lab. Record*, volume 9, May 1931, pages 430–2.

12. The Time Factor in Telephone Transmission, O. B. Blackwell. *Bell Sys. Tech. Jl.*, volume 11, January 1932, pages 53–66. *Bell Lab. Record*, volume 10, January 1932, pages 138–43. AIEE Transactions, volume 51, 1932, pages 141–7. Electrical Engineering, volume 50, October 1931, pages 902–03 (abstract).

13. Two-Way Radio Telephone Circuits, S. B. Wright and D. Mitchell. *Bell Sys. Tech. Jl.*, volume 11, July 1932, pages 368–82. I.R.E., *Proc.*, volume 20, July 1932, pages 1117–30.

14. A Telephone System for Harbor Craft, W. K. St. Clair. *Bell Lab. Record*, volume 11, November 1932, pages 62–6.

15. Voice Frequency Control Terminals for Caribbean Radio Systems, W. A. MacMaster. *Bell Lab. Record*, volume 11, August 1933, pages 369–74.

16. Certain Factors Limiting the Volume Efficiency of Repeatered Telephone Circuits, L. G. Abraham. *Bell Sys. Tech. Jl.*, volume 12, October 1933, pages 517–32.

17. The "Compandor"—An Aid Against Static in Radio Telephony, R. C. Mathes and S. B. Wright. Electrical Engineering, volume 53, June 1934, pages 860–6. *Bell Sys. Tech. Jl.*, volume 13, July 1934, pages 315–32.

18. The Voice-Operated Compandor, N. C. Norman. *Bell Lab. Record*, volume 13, December 1934, pages 98–103.

19. Ship-to-Shore Radio in Puget Sound Area, E. B. Hansen. Electrical Engineering, volume 54, August 1935, pages 828–31.

20. Marine Radio-Telephone Service, F. A. Gifford and R. B. Meader. *Commun. and Broadcast Engg.*, volume 2, October 1935, pages 9–11, 15.

21. A Noise Reducer for Radio-Telephone Circuits, N. C. Norman. *Bell Lab. Record*, volume 15, May 1937, pages 281–5.

22. Radiotelephone Noise Reduction by Voice Control at Receiver, C. C. Taylor. To be presented at the AIEE Pacific Coast convention, August 1937. To be published in Electrical Engineering, August, 1937.

Capacitance Control of Voltage Distribution in Multibreak Breakers

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Summary

This paper discusses the need for good distribution of the voltage among the interrupters of a high-voltage multibreak circuit breaker and the results which have been obtained using capacitances.

Introduction

THE DEVELOPMENT of high-speed circuit breakers capable of interrupting short circuits on 287-kv systems in not over 3 cycles, 0.05 second, has called attention to the importance of the distribution of voltage among a number of interrupters in series. To obtain such high speed of operation all parts must work promptly, quickly, and effectively. Obtaining adequate contact separation to interrupt the circuit and to withstand the restored voltages is accomplished by using a number of interrupters connected in series and operated simultaneously. This construction depends on a division of duty between the individual breaks, each interrupter being loaded with its share so that the interrupting capacity of the pole unit is approximately equal to the sum of the capacities of the units. Uniform distribution of duty is most desirable but it can only be approximated because short circuits of various kinds may occur on either side and the distorting forces cannot be neutralized for all conditions. This paper discusses the problem and capacitance shields which satisfactorily distribute the duty among the interrupters in multibreak circuit breakers.

Factors Determining Voltage Distribution

The distribution of voltages should be suitable during the arcing period, during the extinction of the arc, and after the circuit is interrupted. During the first of these periods all circuit breakers have good voltage distribution. The similar conditions existing in the series gaps of a multibreaker should result in them having approximately equal arc voltages since arcs of equal length carrying equal currents in the same medium under the same conditions have equal voltages.

After the arcs are extinguished and normal voltage has appeared across the breaker, the voltage distribution is determined by the capacitance relationships of the various parts. If all capacitances except those across the gaps could be eliminated, there would be only a simple series circuit composed of equal capacitances. If a voltage were applied across them it would divide equally between the various gaps and this division would be unaffected by the relative potential of the ground. Unfortunately the conditions are not this simple and capacitances to ground and to other parts not at the same potential form a network of circuits so that the voltage distribution is distorted and may depart widely from uniformity. Moreover, different types of short circuits will produce different degrees of distortion. For convenience this distribution will be referred to hereafter in this paper as the static voltage distribution.

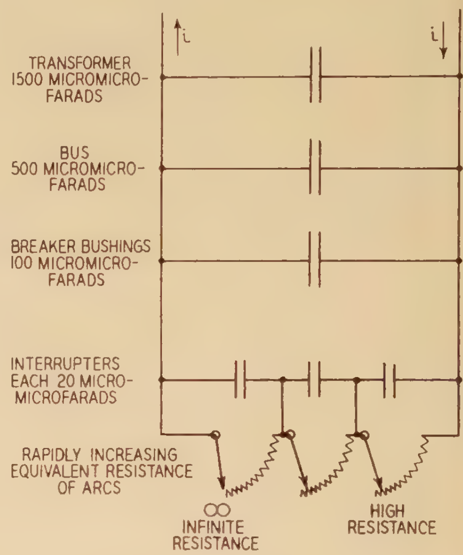

Figure 1. A diagram representing a multibreak circuit breaker at the instant one arc is extinguished

Between the 2 periods already discussed is an important transient period during which the arc space is changing rapidly from a good conductor to a good insulator and during which the voltage distribution is determined first by the arc resistance and later by the electrostatic capacitances of the parts and the relative potentials of the terminals.

When the breaker first starts to open, the current is carried by a continuous metallic path formed by the terminals, contacts, and connecting members. The separation of the contacts introduces arcs which conduct the current and which are acted upon by deionizing agents. As the current approaches zero at the end of a half-cycle, the deionization proceeds more rapidly than ionization

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1. For all numbered references, see list at end of paper.

and conductivity decreases. The conductivity becomes zero at about the time the current reaches zero and the arc does not restrike if the dielectric strength of the arc space is greater than the applied voltage.

The change of the arc space from a conductor to an insulator is not an instantaneous process but consumes an appreciable time interval, up to a few hundred microseconds. This time interval is a variable in an oil circuit breaker because of the conditions which exist between the arc terminals. The space is filled with a nonhomogeneous mixture of gases, oil vapor, and probably drops of oil, all of which are in rapid turbulent motion. A number of independent interrupters carrying currents of the same magnitude will not interrupt in exactly the same manner at exactly the same time. However, if the same current is passed through a series of interrupters operated simultaneously the operation of one unit may influence the operation of the others and effect a synchronization of their action.

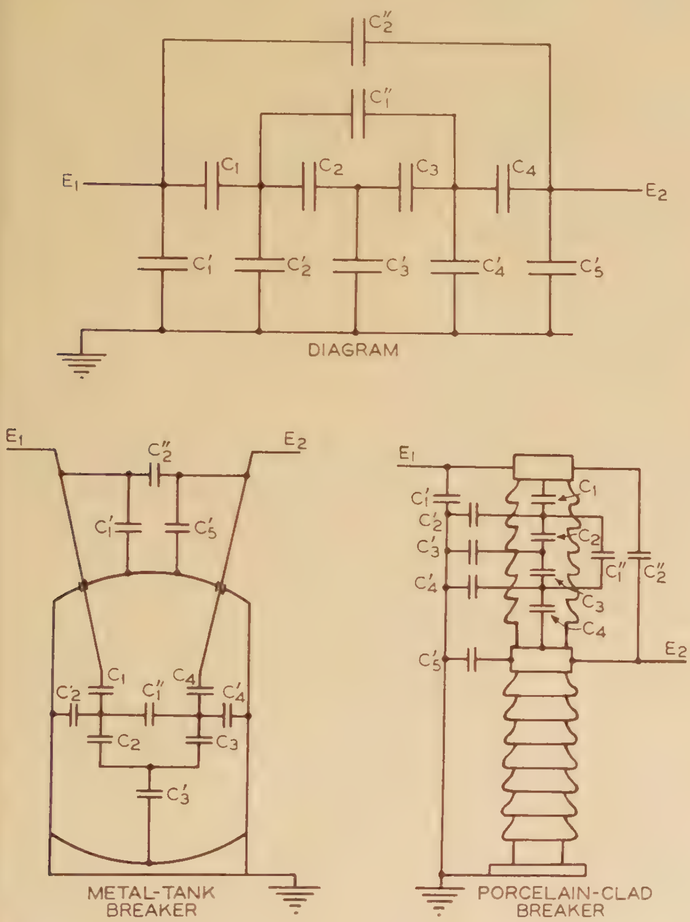


Figure 2. Capacitances associated with the contacts and terminals of 4-break circuit breakers and typical of all multi-break breakers

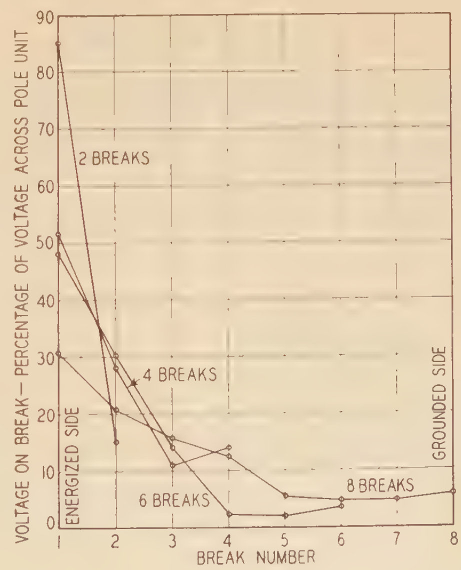
In a breaker without modern interrupting devices, the deionizing activity is relatively weak and the conductivity of the arc space changes relatively slowly. Consequently, the conductivity may be sufficiently high at the current zero to allow the restored voltage to reverse the current and build it up to a few amperes for a short interval before the interruption is finally completed. Since the rate of change of conductivity is relatively low, the differences between series interrupters is so small that this type of performance tends to divide the potential between interrupters equally even though the capacitances would produce a very uneven distribution.[1]

More effective interrupters have a higher rate of deionization and the change from a conducting arc to an insulating space is more rapid. Additional phenomena associated with the capacitances of the circuit assist in keeping the voltage divided between interrupters. These interrupters may deionize the space so rapidly that the dielectric strength required for interruption is obtained at current zero or even before the normal current zero. Oscillograms of circuit-breaker operations in which unstable arc conditions resulted in the arc being extinguished before the normal current zero have been discussed before the Institute.[2,3] This is the other extreme in breaker operation and in this case also the interrupters distribute the voltage among themselves. However, the resistances of the arc spaces will not do it since the resistances become infinite, but the capacitance currents and impedances become important and take over the function. The capacitances not only control the voltage distribution after the arcs are extinguished but also assist in sychronizing the deionization. Exact knowledge of this phenomena is lacking and the following is offered as a possible explanation.

The extreme in this type of operation is characterized by a very rapid increase in effective resistance of the arc as the current approaches zero. It is so great that the arc may become unstable and be suddenly extinguished from a current of about 10 amperes or less.[3] The conditions existing at such an instant may be represented by the diagram in figure 1. The small capacitances are chosen to represent a circuit having a high rate of voltage recovery.

When in the last few microseconds of a half-cycle of current one interrupter is able suddenly to produce infinite resistance between its contacts, the current flowing through the interrupter is diverted into the various ca-

Figure 3. Voltage distribution in multi-break oil circuit breakers having metal tanks and no shielding devices. The data are for 2, 4, 6, and 8 breaks with one terminal energized and the other grounded



pacitances, c, in parallel with it. This current raises the voltage across the pole unit, starting at a maximum rate, de/dt, which depends on the magnitude, i, of the current flowing at the instant of arc rupture

$$\frac{de}{dt} = \frac{i}{c}$$

Because the capacitance of the interrupter is small compared to the other capacitances, the current flowing into it is almost negligible. In the case shown in figure 1 it would be only

$$i \times \frac{20 \text{ micromicrofarads}}{1{,}500 + 500 + 100 + 20 \text{ micromicrofarads}}$$

or about 0.01 i. Therefore the current through the other series interrupters would decrease rapidly from i to 0.01 i as their capacitances were discharged through the residual ionization in the arc spaces. However, all of these interrupters are similar and have about the same characteristics. Oscillograms show that at least one has been able to force its current to zero with more than its share of voltage across it. Therefore, it seems reasonable that the reduced energy input into the other interrupters would result in rapid increases in their effective resistances and that the voltages across them would not completely collapse. Since the change from finite to infinite resistance could hardly be instantaneous in the arc path of even the first interrupter, it appears probable that when one starts

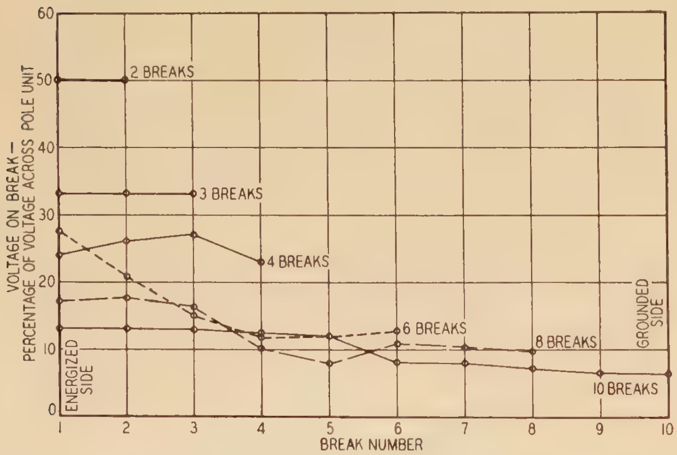


Figure 4. Voltage distribution in multibreak oil circuit breakers having metal tanks and shielding devices. The data are for 2, 3, 4, 6, 8, and 10 breaks with one terminal energized and the other grounded and when compared with figure 3 show the improvement obtained by shielding

to choke the current the others assist and the voltages across them are approximately equal.

The larger the capacitances across the interrupters or the more closely they are coupled to large capacitances such as shields, the less will be the voltage collapsing effect of small inequalities in the rates of deionization and the more uniform will be the voltage distribution at the time all units become nonconducting. After the arc spaces become deionized, the capacitances determine the

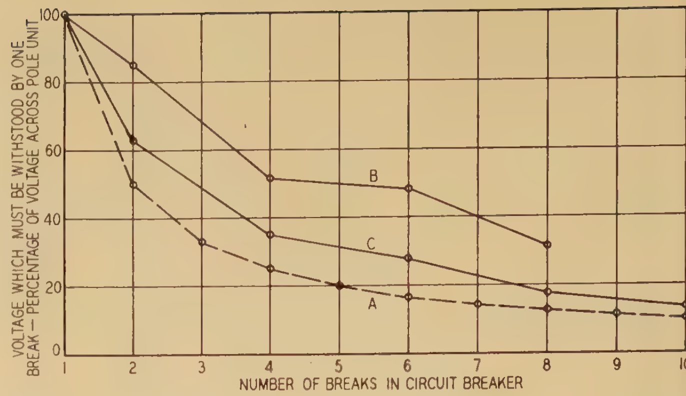


Figure 5. Shielding reduces the maximum voltage which can appear across any one break

Curve *A*—Minimum possible (assuming uniform distribution of voltage)
Curve *B*—Measured without shielding
Curve *C*—Measured with shields

subsequent changes in the voltage across each interrupter.

Since the static voltage distribution is of importance in itself and is also a determining factor in the voltage distribution during interruption and since it is much more readily determined, it is taken as a criterion of the electrical stresses applied on the various breaks in a multibreak circuit breaker.

Voltage Distribution in Breakers

The static voltage distribution depends upon the capacitances of the various parts of the breaker with respect to each other and with respect to ground and upon the voltages applied to the terminals of the breaker. A network representing a 4-break circuit breaker is shown in figure 2. Obviously still more capacitances are present and could be shown but generally they are relatively unimportant. This network shows that fundamentally the problem is the same in either a metal-tank breaker or in a porcelain breaker. The relative capacitances to ground are greater in a grounded metal-tank breaker but satisfactory distribution may be obtained in either case by adequate shielding means.

The relative potentials applied to the terminals of the breaker affect the distribution since some of the capacitances are to ground and their effect will depend on the potentials of the terminals. The distribution of the voltage between breaks is independent of the magnitude of the voltage between terminals, because none of the circuit constants change with voltage. Moreover, it is independent of frequency since all of the components of the circuit are capacitances and react in the same manner to changes in frequency. This is particularly important in connection with the voltage recovery transient. Grounding of the neutral of the system directly or through impedances and the location of the principal impedances determine the voltage applied across a pole unit but need not be discussed here since the voltage distribution in the breaker depends only on the relative potentials of the 2 terminals with respect to ground.

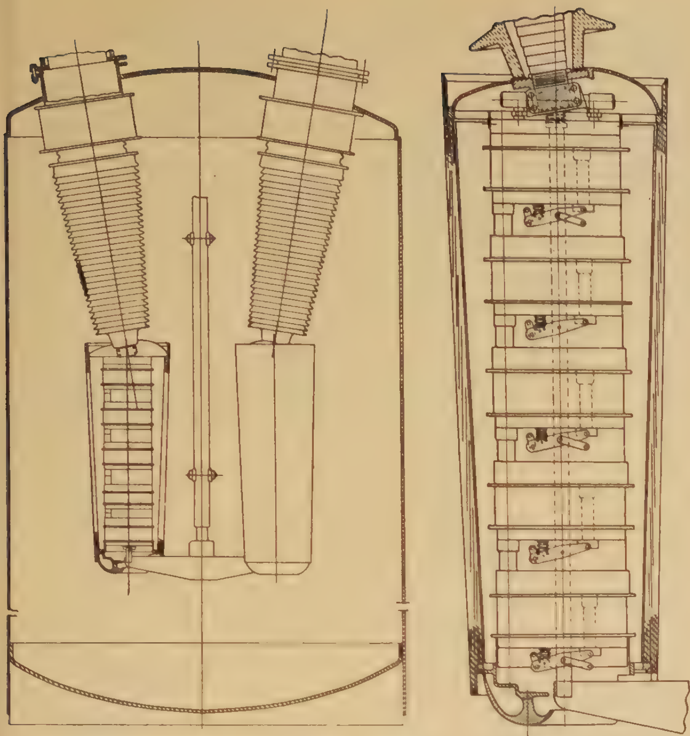


Figure 6. Shields used in a 287-kv oil circuit breaker

The best distribution is obtained usually with the connection corresponding to the opening of line-to-line voltage across a single pole because the recovery voltage after current zero impresses equal and opposite potentials on the terminals. The ground potential being midway between the terminal potentials results in a symmetrical distribution of voltage between interrupters and usually a minimum of distortion. A corresponding connection has been used in high-power laboratories for applying 264 kv across a pole unit. The testing transformers were insulated for only 132 kv to ground but by connecting the primaries of 2 of them to the same phase and the secondaries in series with the midpoint grounded 264 kv was obtained between terminals of the breaker.

A more usual condition is a line grounded on one side of the breaker. This is simulated by grounding one terminal of the breaker and energizing the other.

A 3-phase ungrounded short circuit would apply, to the first pole to interrupt, potentials of phase voltage on one terminal and minus half of phase voltage on the other. This is a condition which is between the 2 others with respect to the voltage distribution but it is important because of the magnitude of the voltage between terminals, 87 per cent of line-to-line voltage.

The magnitudes of the voltages impressed on the pole unit will be determined by the system and by the nature of the short circuit. The maximum voltage on any interrupter is determined for the various conditions by the impressed voltages on the pole unit and the corresponding voltage distributions.

The 3 important conditions for voltage distribution are given in table I in terms of the relative test potentials applied to the terminals of the pole unit. It should be noted that E is the total test voltage between terminals and has no relation to the magnitude of the voltages impressed by the corresponding short circuits.

The poorest distribution is obtained with a grounded short circuit near the breaker terminal so this will be used as the basis of comparision to show the need for shielding and its effectiveness.

The voltage distribution in metal-tank breakers having various numbers of breaks and no special provisions to insure proper voltage distribution are given in figure 3. The data are taken from tests on 2-, 4-, 6-, and 8-break circuit breakers of experimental designs. The variations in the arrangements of contacts cause the curves to be of slightly different nature and account for the irregularities in the spacing of the curves at any particular break. The significant point is the inherent unequal distribution of voltage between interrupters in a multibreak circuit breaker having no special shielding provisions. The interrupter next to the bushing having potential is required to withstand more than twice the average voltage for the 4-, 6-, and 8-break circuit breakers. These data show that increasing the number of breaks without taking steps to insure proper voltage distribution does not result in reducing the voltage per gap approximately in proportion to the number of gaps. In fact, the most of the gaps take very little voltage and are actually a liability since they will produce just as much arc energy during the arcing period as the gap which has to withstand the most voltage at the interruption.

The voltage distribution can be modified and made to approach the ideal by the use of capacitances which reduce or eliminate the effect of those causing distortion. Improved distribution obtained with capacitance shields is shown in figure 4. The 2- and 3-break circuit breakers were single pole experimental types and were intended for operation with one side grounded. Consequently, the shielding was designed for this condition only and uniform distribution was obtained. The 6 - and 8-break breakers are the same ones that were tested unshielded and the data are directly comparable. They were designed for

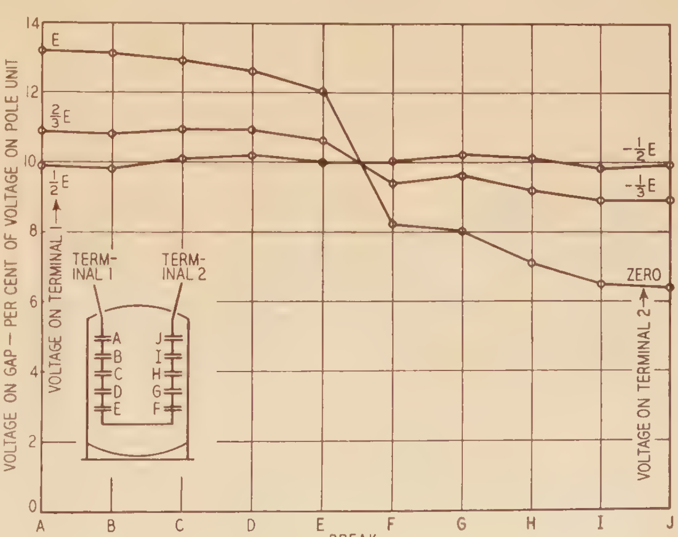


Figure 7. Voltage distribution in a shielded 10-break circuit breaker under 3 conditions of applied voltage

Table I

Condition	Potential of the Terminals E_1	E_2
1. A grounded short circuit near the breaker terminal	E	Ground
2. First phase to clear on an ungrounded 3-phase short circuit on a grounded system	$+{}^2/_3E$	$-{}^1/_3E$
3. An ungrounded, line-to-line, single-phase short circuit through a single pole. (A test condition)	$+{}^1/_2E$	$-{}^1/_2E$

Note: E is the voltage across the pole unit and will not have the same value for each of the conditions given above.

grounding on either side so the shielding was symmetrical and the results approached but did not reach uniform distribution. The 6-break assembly is slightly under-shielded. In the 8-break assembly the fourth and fifth interrupters were slightly different from the others and not quite as effective. Consequently, the shielding was designed so that these 2 interrupters would get less voltage than the others. How well this was controlled is shown by the curves.

The advantages gained by shielding are clearly shown in figure 5. The ordinates are the maximum voltage on any one interrupter in percentage of the voltage applied across the pole unit.

Curve *A* indicates the percentage for uniform distribution in breakers, having from one to 10 interrupters. Curve *B* indicates the percentage as measured in some unshielded circuit breakers. Curve *C* indicates the percentage as measured in shielded breakers and shows a big improvement due to shielding. This figure shows that for a given service, about the same interrupting ability is required of the interrupters for the unshielded 8-break circuit breaker, as for the suitably shielded 4-break circuit breaker. The shielded breaker having half the number of interrupters, has half the total arc length and half the arc energy. The use of shielding in the 8-break circuit breaker permits the use of interrupters of about half the voltage interrupting ability and therefore, approximately half the arc length, half the arc duration, and an even smaller fraction of the arc energy.

Devices Used for Controlling Voltage Distribution

The shielding devices which have produced the results already discussed are of new design. One recently developed for 287-kv breakers and described in a paper before the Institute[4] is shown in figure 6. It consists of a conical tube wound from treated paper and foil. Its construction is similar to that of a condenser bushing but differs in the location and length of the foil layers since the potential is applied between the ends of the shield instead of between the inside and the outside. The shield has an approximately uniform potential gradient from one end to the other on both the inside and outside surfaces. The interrupters located at uniform intervals inside it share the voltage equally among them. Each contact is shielded from ground and has a large capacitance to a layer of foil which has approximately the same potential as the contact. Two shields are used in a pole unit, each shield containing half of the interrupters. The large capacitances of the shields minimize the distorting effect of the capacitance to ground of the moving contact and connected metal parts. This divides the voltage between the 2 halves of the pole unit and the 2 shields divide these portions among the individual grids.

The results obtained with this shield are shown in figure 7 which gives the results of measurements under the 3 conditions of table I and shows the relations between them.

A similar shield was used during experimental work on 4 interrupters. The maximum voltage which could be interrupted was about 88 kv although individually the units could interrupt 30 kv. The electrical field inside the shield was then measured, figure 8, and found to give a voltage distribution of 24, 26, 33, and 17 per cent which indicated that one of the 4 units was being stressed to about 33 per cent of 88 kv or 29 kv. Subsequently an assembly of 4 35-kv interrupters having a voltage distribution of 24, 26, 27, and 23 per cent was tested and found to interrupt 132 kv successfully. The voltage on one unit should have been about 27 per cent of 132 kv or 35.6 kv.

Table II. Voltage Limitations of Interrupter Assemblies Having Good Voltage Distribution

Number of Units in Series	Voltage Limitation (Kilovolts)	Voltage on One Interrupter Per Cent	Kilovolts
1	35 to 40	100	35 to 40
2	65 to 75	50	32.5 to 37.5
3	100 to 115	33.3	33.3 to 38.3
4	132 or more	27	35.6 or more

The 35-kv interrupters were tested also in 2 and 3 unit assemblies with uniform distribution and the results substantiated the voltage distribution measurements as shown by the data in table II.

These series of tests demonstrated clearly the value of the static voltage distribution as a criterion of the voltage conditions existing during interruption.

Methods of Measuring Voltage Distribution

The measurement of the voltage distribution in oil circuit breakers presents some interesting problems because of the presence of oil, the variation in the breakdown of gaps in oil, the difficulty or impossibility of locating shielded leads in equipotential surfaces, and the difficulty of making observations of phenomena below the oil surface or within the shields. A modification of the sphere gap method was selected. Gas discharge tubes replaced the sphere gaps and special viewing or detecting means were used in the determination of the breakdown. One assembly of 4 interrupters prepared for test but not yet covered by the shield, is shown in figure 9. Two small neon discharge tubes *A* having a breakdown voltage of about 60 volts are mounted adjacent to the metal assem-

blies between gaps. One lead from each tube is connected to the adjacent metal parts and the other, a flexible insulated lead is connected to a piece of metal fastened to a heavy cord. The cord passes vertically through metal guides along the assembly, the upper end goes directly to the manhole at the top of the breaker, and the lower end passes around the lower end of the shield and thence upward to the manhole. After the breaker is filled with oil, the lead can be pulled into contact with a guide, thereby connecting the tube across either the gap above the tube or the gap below the tube (as shown in the illustration). By stopping the cord midway between the end positions the flexible lead is held adjacent to the metal parts where it will exert practically no disturbing effect while measurements are being made with the other tube. This facilitates testing as it reduces the amount of oil handling.

The light from the small tube would be invisible through the oil, so a glass tube, which is sealed at the bottom and

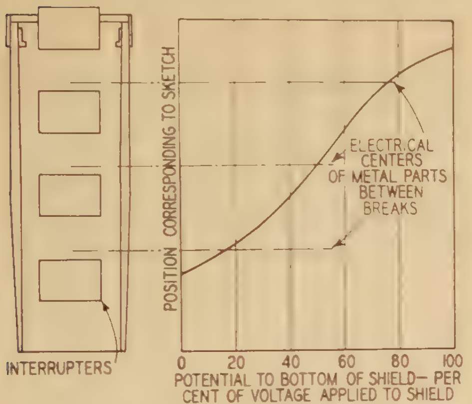


Figure 8 (above). The electrical field inside a shield used in an experimental 4-break circuit breaker

Figure 9 (right). An assembly of interrupters with equipment for voltage distribution measurements mounted on it

mounted directly above the discharge tube, is used to transmit the light upward to a point above the surface of the oil, where it is deflected by a prism to the manhole.

The test apparatus has little influence on the voltage distribution. The glass, Micarta, string, and air displace a small amount of oil and change slightly the dielectric, but the effect is negligible. The discharge tubes themselves have little capacitance and the leads are as short as possible and are located where they cause a minimum of error. Consequently the capacitance added to the capacitance of an interrupter by connecting the tube across it is relatively small and approximately constant, and a correction for it is easily made.

Voltage is applied by means of 2 variable-voltage potential test sets having a range of zero to 30 kv and connected to a common source of voltage, so that the secondary voltages are 180 degrees out of phase.

For tests with one terminal grounded, the procedure is as follows. By manipulation of the cords, a tube is connected across the gap under test. Potential is then applied to a terminal and increased until the voltage appearing across the gap under test is sufficient to cause the tube to break down and glow. The applied potential is recorded and 2 or 3 additional readings made as a check to be sure that the observer noticed the first breakdown. The percentage of the voltage appearing across the gap can then be obtained by dividing the breakdown voltage of the tube by the applied voltage and multiplying by 100 per cent. The leads to the terminals of the breaker are then reversed which in effect prepares for the test on the corresponding gap on the other side of the breaker. In this way only one assembly of interrupters needs to be fitted with tubes for test. After all the gaps have been tested, the percentages are added but, due to the increase in the capacitance across each gap when the tubes are connected for measurements, the sum is not 100 per cent. Since the effect of the apparatus has been about the same on each gap a constant multiplying factor is used in raising each percentage so the sum equals 100 per cent.

For tests with both terminals energized the procedure is similar but care must be taken that the potentials applied to the terminals are always in the correct ratio.

The consistency of the results and their agreement with

Table III. Voltage Distribution on 10-Break Oil Circuit Breaker Equipped With Shields Around Contacts

Data From Witness Test

Grid	Voltage Applied (Volts) Term. I	Term. II	Average	Tube Breakdown Volts	Voltage on Gap (Per Cent) Reading	Corrected	Calculated
A	446, 445, 445	Ground	445.3	51.75	11.6	13.2	12.9
B	452, 452, 452	Ground	452.0	51.75	11.44	13.1	13.2
C	517, 514, 516	Ground	515.6	58.3	11.28	12.9	13.0
D	531, 530, 528	Ground	529.6	58.3	11.05	12.6	12.3
E	536, 535, 534	Ground	535	56.0	10.5	12.0	11.6
E (F)	Ground	786, 784, 784	785.3	56.0	7.17	8.2	7.6
D (G)	Ground	830, 830, 830	830	58.3	6.99	8.0	7.6
C (H)	Ground	924, 922, 922	922.6	58.3	6.2	7.1	7.6
B (I)	Ground	888, 888, 888	888	51.75	5.72	6.5	7.4
A (J)	Ground	920, 920, 920	920	51.75	5.63	6.4	6.8
				Total	87.58	100	100

calculations made before the shields were built are shown by the typical data presented in table III.

The results of tests made with tubes having breakdown voltages of 60 volts were checked by similar tests with tubes having a breakdown of about 30 kv. The tubes were larger and were inserted in the spaces between interrupters. This made viewing from above still more difficult so a choke coil was inserted in the lead to one terminal and one of the 60-volt discharge tubes was connected across it. This lead was grounded and the other connected to a high potential testing transformer. The voltage was raised until the 30-kv tube broke down. The discharge caused the 60-volt tube to glow. Data taken in this manner with one terminal energized and the other grounded gave the same voltage distribution as the data taken with the lower-voltage tubes. The other conditions were not tested with the high-voltage tube because of the greater difficulty in the manipulation of the higher potentials and the close agreement with the data more easily obtained at lower voltages.

Conclusions

The efficiency of multibreak circuit breakers depends on the distribution of the voltage between the interrupters.

The presence of grounded parts near the interrupters and the capacitances between interrupters tend to distort the voltage distribution and to decrease the efficiency of the breaker.

Voltage distribution in multibreak circuit breakers can be controlled by capacitance shielding, so that each interrupter does its share under all short-circuit conditions.

Interrupting tests justify the use of static voltage distribution as a criterion of the voltage distribution during an interruption.

The distribution can be calculated and measured.

References

1. The Development of the Single Break Oil Circuit Breaker for Metal Clad Switchgear, D. R. Davis and C. H. Flursheim. *Journal* of the IEE, August 1936, pages 128–78.

2. Arc Extinction Phenomena in High Voltage Circuit Breakers, R. C. Van Sickle and W. E. Berkey. AIEE Transactions, volume 52, 1933, pages 850–60.

3. Breaker Performance Studied by Cathode Ray Oscillograms, R. C. Van Sickle. Electrical Engineering (AIEE Transactions), 1935.

4. Circuit Breakers for Boudler Dam Line, W. M. Leeds and H. M. Wilcox. Electrical Engineering (AIEE Transactions), 1936.

Polyphase Rectifier Metering

IN PRESENTING a paper "The Metering of Mercury-Arc Rectifier Supplies and Outputs" at a recent meeting of The Institution of Electrical Engineers in London, England, C. Dannatt (A'29) research engineer for the Metropolitan-Vickers Electrical Company, Manchester, described in detail both the theoretical and practical problems involved in accurate metering of polyphase mercury-arc rectifier input and output quantities. In this 12-page paper, containing 11 illustrations and 8 tables, Mr. Dannatt stressed the essential that an accurate meter for rectifier inputs must be so constructed that its calibration is independent of frequency. The rigorousness of this requirement decreases, however, if the number of rectifier phases is increased, or if the wave form of the voltage applied to the rectifier transformer is improved. Table IV, which is reproduced from the paper, shows the variation in metering errors as the number of phases is changed.

Table IV

	3-Phase Rectifier*		6-Phase Rectifier**	
	True Values	Meter Values	True Values	Meter Values
Power factor	0.71	0.89	0.89	0.94
Reactive kilovolt-amperes	71	37.2	45.6	33.1
Total kilovolt-amperes	100	79.5	100	94.8
Distortion power (P_D)	60.5		31.3	

* With a ratio of line reactance to transformer reactance of 0.85.
** With a ratio of line reactance to transformer reactance of 0.91.

A mathematical series describing the energy associated with current and voltage of distorted wave forms consists of a steady term and a series of pulsating terms, so that a meter used to measure energy must maintain its accuracy at frequencies as high as the component frequencies of the composite wave form. The proportion of pulsating energy to total energy decreases rapidly with an increase in the number of phases; consequently, serious difficulty in metering rectifier input is most likely to occur in rectifiers of low numbers of phases.

Except for known bad performance with respect to changes in frequency, the ordinary induction type of meter has so many advantages that its inherent errors were investigated very carefully to determine whether they were of sufficient importance to nullify the advantages of this type of meter for measuring rectifier input. The conclusion from the tests was that the error of a modern well-designed induction meter connected to rectifier supplies is not likely to exceed one per cent for a 3-phase connection, or 0.5 per cent for a 6-phase connection, provided that the meter is adjusted to register correctly with sinusoidal current and voltage.

The satisfactory performance of the induction meter encouraged the author to try other types of meters that may be used on either alternating current or direct current, and that consequently are less dependent on frequency than the induction meter in calibration. The Thomson motor type of meter is in this category, and was found to be sufficiently independent of frequency to make it an accurate instrument for rectifier power-input measurements, if no shunt is used across the field coils.

This type of meter is said to be satisfactory also for measuring the d-c output of polyphase rectifiers; satisfactory accuracy depends chiefly upon reducing the ripple component of the output, but appreciable inaccuracy of the meter may result from its use on 2- or 3-phase circuits with very little smoothing of the d-c output.

Discussions

Of AIEE Papers—as Recommended for Publication by Technical Committees

On THIS and the following 16 pages appear discussions submitted for publication, and approved by the technical committees, on papers presented at the sessions on tensor analysis, synchronous machinery, and protective devices at the 1937 AIEE winter convention, New York, N. Y., January 25–29, and on one paper not presented at an AIEE meeting. Authors' closures, where they have been submitted, will be found at the end of the discussion of their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at any AIEE meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, AIEE headquarters, 33 West 39th Street, New York, N. Y.

A Single-Element Polyphase Directional Relay

Discussion and author's closure of a paper by A. J. McConnell published in the January 1937 issue, pages 77–80, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 27, 1937.

G. W. Gerell (Union Electric Light and Power Company, St. Louis, Mo.): Mr. McConnell's paper brings to mind certain difficulties which our company has been experiencing with single-phase power directional relays. On rather too frequent occasions reverse power relays have operated during faults behind the relay. In most cases these incorrect operations occurred during single-phase ground faults. Invariably the relay operating falsely was not connected to the faulted phase. It should be noted that these operations have always taken place on systems grounded solidly at 2 or more points. A typical circuit arrangement would consist of 2 33-kv circuits supplying power to a substation. The circuits would be energized from the 13,800-volt power plant bus through 13.8/33 kv delta-wye grounded transformer. At the substation end the circuits would be bussed at 33 kv. The reverse power relays are located on the line oil switches at the substation end. No incorrect operations have been recorded on a number of other circuits, arranged in a similar manner, but bussed at the substation end through 33/4.5 kv transformer banks on the low-tension side.

Extremely low power factors, causing a reversal of torque in the relay may account for these operations, but I am more inclined to believe that they are caused by the relatively high currents flowing in the ungrounded conductors during a one-phase-to-ground fault. The *net* power flow at the point where the false operations occur, is of course, in such a direction to prevent incorrect operation, but in the ungrounded phases it is not necessarily so.

A polyphase relay, measuring net power in a 3-phase circuit, as Mr. McConnell has described, should effectively prevent operations so frequently experienced with the single-phase type of directional relays.

The phenomena reported here, occurs more generally on systems solidly grounded at several points, and such being the case, the question naturally arising is—why are the single-phase relays invariably applied to such systems. Polyphase directional relays were available, I believe, even before the advent of the single-phase type. Moderately high-speed polyphase relays have been available, at least during the last 6 or 7 years. For some reason or the other, they have been applied less frequently as time goes on.

Concerning a method of preventing incorrect operations on existing installations of the single-phase relays it is suggested that setting the over-current element of the directional relay for a pick-up in excess of the calculated value of current flowing in the ungrounded phases may constitute a solution, provided the setting is practical.

J. H. Neher (Philadelphia Electric Company, Philadelphia, Pa.): The increased use of pilot protective systems, of either the carrier current or metallic pilot-wire types, has brought about the need for a polyphase directional relay capable of high-speed and positive-contact operations. Mr. McConnell is to be congratulated on the development of such a relay which at the same time fulfills the demand for a rugged general purpose polyphase directional relay comparable in cost to, but occupying considerably less space than the present forms of such relays.

When voltage restraint is added to a directional element the resultant combination may be described as a directional distance fault detector, the range of which is a function of the angle of departure from the angle of maximum torque in the directional circuit and which is a maximum when this angle of departure is zero. In certain relay arrangements it is desirable to make use of this property such as for instance in the case of the starting unit of a reactance type distance relay.

Under such conditions it is desirable that the range of the relay be substantially the same for both 3-phase and phase-to-phase faults. The maximum range of a single-phase directional element with voltage restraint for a phase-to-phase fault is about 86 per cent of the range for a 3-phase fault, while in the case of a polyphase element with the quadrature connections, the range for a phase-to-phase fault is only 50 per cent of that for a 3-phase fault.

It appears that the connections shown in figure 2 will also have a maximum range of 50 per cent in the case of a phase-to-phase fault. As Mr. McConnell has pointed out, however, the construction of this new element is such that a number of other connections may be utilized, and possibly one can be found which will result in ranges for the 2 types of faults which are more nearly equal.

E. W. Kimbark (Massachusetts Institute of Technology, Cambridge): The correct working of practically every protective relay scheme, from simple overcurrent protection to carrier-current relaying, depends on directional relays, either of the single-phase type or of the polyphase type. Therefore it is important to know with accuracy what conditions limit the correct operation of such relays; and it would be desirable to have a complete mathematical analysis of their performance, like the analysis of distance relays which has been so ably achieved by Messrs. Lewis and Tippett. The paper by Mr. McConnell makes a good start at such an analysis for the polyphase type of directional relay, particularly by expressing the relay torque for each of 2 different connections in terms of the flow of positive- and negative-sequence power in the protected line, thereby enabling us to see that each of these 2 components of power contributes a suitable component of torque.

The directions of flow of vector power due to a short circuit on a 3-phase network are as follows in terms of symmetrical components: positive-sequence power flows toward the fault; while negative-sequence and zero-sequence power (if one or both are produced by the type of fault in question) flow away from the fault. The relative magnitudes of the positive-, negative-, and zero-sequence powers at a relay location depend on the type of fault, on the division of power of each sequence between the 2 ends of the faulted line, and on the distance between the fault and the relay.

(The relations derived in appendixes I *B* and II *B* of the paper for a dead phase-to-phase fault are exact only if the relay is close to the fault and only if the line is open at the far end, or if the positive- and negative-sequence powers divide between the two ends of the line in the same ratio.) Although the power at a relay location may consist of 1, 2, or 3 sequence components, mixed in various proportions, nevertheless the flow of each component is in the direction stated above; and any component which is present, or a combination of 2 or 3 of them, may be used to indicate the direction of the fault location. If all 3 components are used, the relay torque may be expressed by

$$\text{real part of } [k_1 \boldsymbol{E}_1 \bar{\boldsymbol{I}}_1 \angle\theta_1 + k_2 \boldsymbol{E}_2 \bar{\boldsymbol{I}}_2 \angle\theta_2 + k_0 \boldsymbol{E}_0 \bar{\boldsymbol{I}}_0 \angle\theta_0]$$
$$= k_1 E_1 I_1 \cos(\phi_1 + \theta_1) + k_2 E_2 I_2 \cos(\phi_2 + \theta_2) + k_0 E_0 I_0 \cos(\phi_0 + \theta_0) \quad (1)$$

(See end of discussion for notation used.) It is desirable that θ_2 and θ_0 should differ by approximately 180 degrees from θ_1 so that the sign of each of the 3 terms of the expression will be the same when negative-sequence and zero-sequence power are flowing in the direction opposite to that of the positive-sequence power (that is, when ϕ_2 and ϕ_0 are approximately 180 degrees from ϕ_1). This is on the assumption that the power factor is approximately the same for each sequence; it may differ somewhat for different sequences, and the positive-sequence power factor may vary with the type of fault. Since the positive- and negative-sequence torque terms are ordinarily obtained, not from a positive-sequence element and a negative-sequence element, but from several elements working on phase currents and voltages, k_1 and k_2 are necessarily equal, while θ_1 and θ_2 depend on θ (defined below) and on the relay connections.

The torque of each single-phase directional element is given by the

$$\text{real part of } k\, \boldsymbol{E}\, \bar{\boldsymbol{I}} \angle\theta = kEI \cos(\phi + \theta) \quad (2)$$

and the combined torque of several single-phase elements of identical construction, or of an equivalent polyphase element, is given by

$$\text{real part of } k \angle\theta \sum \boldsymbol{E}\bar{\boldsymbol{I}} \quad (3)$$

The factor

$$\sum \boldsymbol{E}\bar{\boldsymbol{I}}$$

for various connections of 3 single-phase elements, using either *Y* (line-to-neutral) or Δ (line-to-line) voltages and either *Y* or Δ currents, may be expressed as follows:

$$\boldsymbol{E}_a\bar{\boldsymbol{I}}_a + \boldsymbol{E}_b\bar{\boldsymbol{I}}_b + \boldsymbol{E}_c\bar{\boldsymbol{I}}_c = 3(\boldsymbol{E}_0\bar{\boldsymbol{I}}_0 + \boldsymbol{E}_1\bar{\boldsymbol{I}}_1 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2) \quad (4)$$

$$\boldsymbol{E}_a\bar{\boldsymbol{I}}_b + \boldsymbol{E}_b\bar{\boldsymbol{I}}_c + \boldsymbol{E}_c\bar{\boldsymbol{I}}_a = 3(\boldsymbol{E}_0\bar{\boldsymbol{I}}_0 + \boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 120 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 240) \quad (5)$$

$$\boldsymbol{E}_a\bar{\boldsymbol{I}}_c + \boldsymbol{E}_b\bar{\boldsymbol{I}}_a + \boldsymbol{E}_c\bar{\boldsymbol{I}}_b = 3(\boldsymbol{E}_0\bar{\boldsymbol{I}}_0 + \boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 240 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 120) \quad (6)$$

$$\boldsymbol{E}_a\bar{\boldsymbol{I}}_A + \boldsymbol{E}_b\bar{\boldsymbol{I}}_B + \boldsymbol{E}_c\bar{\boldsymbol{I}}_C = 3\sqrt{3}\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 270 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 90) \quad (7)$$

$$\boldsymbol{E}_a\bar{\boldsymbol{I}}_B + \boldsymbol{E}_b\bar{\boldsymbol{I}}_C + \boldsymbol{E}_c\bar{\boldsymbol{I}}_A = 3\sqrt{3}\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 30 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 330) \quad (8)$$

$$\boldsymbol{E}_a\bar{\boldsymbol{I}}_C + \boldsymbol{E}_b\bar{\boldsymbol{I}}_A + \boldsymbol{E}_c\bar{\boldsymbol{I}}_B = 3\sqrt{3}\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 150 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 210) \quad (9)$$

$$\boldsymbol{E}_A\bar{\boldsymbol{I}}_a + \boldsymbol{E}_B\bar{\boldsymbol{I}}_b + \boldsymbol{E}_C\bar{\boldsymbol{I}}_c = 3\sqrt{3}\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 90 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 270) \quad (10)$$

$$\boldsymbol{E}_A\bar{\boldsymbol{I}}_b + \boldsymbol{E}_B\bar{\boldsymbol{I}}_c + \boldsymbol{E}_C\bar{\boldsymbol{I}}_a = 3\sqrt{3}\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 210 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 150) \quad (11)$$

$$\boldsymbol{E}_A\bar{\boldsymbol{I}}_c + \boldsymbol{E}_B\bar{\boldsymbol{I}}_a + \boldsymbol{E}_C\bar{\boldsymbol{I}}_b = 3\sqrt{3}\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 330 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 30) \quad (12)$$

$$\boldsymbol{E}_A\bar{\boldsymbol{I}}_A + \boldsymbol{E}_B\bar{\boldsymbol{I}}_B + \boldsymbol{E}_C\bar{\boldsymbol{I}}_C = 9\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2) \quad (13)$$

$$\boldsymbol{E}_A\bar{\boldsymbol{I}}_B + \boldsymbol{E}_B\bar{\boldsymbol{I}}_C + \boldsymbol{E}_C\bar{\boldsymbol{I}}_A = 9\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 120 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 240) \quad (14)$$

$$\boldsymbol{E}_A\bar{\boldsymbol{I}}_C + \boldsymbol{E}_B\bar{\boldsymbol{I}}_A + \boldsymbol{E}_C\bar{\boldsymbol{I}}_B = 9\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 240 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 120) \quad (15)$$

The following 2-element combination is also of interest:

$$\boldsymbol{E}_A\bar{\boldsymbol{I}}_C - \boldsymbol{E}_C\bar{\boldsymbol{I}}_A = 3\sqrt{3}\,(\boldsymbol{E}_1\bar{\boldsymbol{I}}_1\angle 270 + \boldsymbol{E}_2\bar{\boldsymbol{I}}_2\angle 90) \quad (16)$$

Equations 7, 10, and 16 are for the 90-degree connection (equation 10 representing its usual form); equations 5 and 14 are for the 60-degree connection, which is equivalent to the one recommended in the paper for the new polyphase relay; and equations 9 and 12 are for the 30-degree connection (equation 12 the usual form.) A comparison of the expressions just mentioned, substituted in (3), with equation 1, yields the following values of θ_1 and θ_2:

Connection	θ_1	θ_2
90-degree	$\theta - 90$	$\theta + 90$
60-degree	$\theta - 60$	$\theta + 90$
30-degree	$\theta - 30$	$\theta + 30$

By way of comparison, assume that for each connection the positive-sequence torque is made a maximum at 30 degrees lag ($\theta_1 = -30$). This assumption determines a different value of θ for each connection, and the value of θ determines the values of θ_2 and of $\theta_2 - 180$:

Connection	θ_1	θ	θ_2	θ_2–180
90-degree	−30	60	150	− 30
60-degree	−30	30	90	− 60
30-degree	−30	0	30	−150

The values of ($\theta_2 - 180$) are the phase angles of the negative-sequence current with respect to the negative-sequence voltage for maximum torque, considering that the negative-sequence vector power is substantially opposite in direction to the positive-sequence; thus, the 90-degree connection gives maximum torque at 30-degree lag (equal to the lag at which the positive-sequence power gives maximum torque); the 60-degree connection at the greater lag of 90 degrees; and the 30-degree connection at the still greater lag of 150 degrees. Since so great a lag would never be obtained, the negative-sequence torque would be relatively low in the 30-degree connection, and possibly even reversed in direction. For this reason the 90-degree and 60-degree connections appear preferable to the 30-degree connection, even though the latter would probably operate correctly.

The connections just discussed give no zero-sequence torque, with the exception of the form of 60-degree connection represented by equation 5. For this case $k_0 = k_1$, and $\theta_0 = \theta + 180$. Assuming as before that $\theta_1 = -30$, there results $\theta_0 - 180 = 30$; maximum zero-sequence torque is obtained with current leading by 30 degrees. This is not the best relation that could be imagined, because the zero-sequence current will frequently lag by a considerable angle, giving a low or even reversed torque, though probably seldom strong enough to overweigh the positive- and negative-sequence torques. If desired, the zero-sequence torque can be eliminated by connecting the relay voltage windings in *Y* with no neutral connection. A more reliable and flexible way of introducing a zero-sequence torque is to use an electrically separate mechanically coupled zero-sequence element as described in the paper; by this means k_0 and θ_0 can be given any desired values. It would be interesting to know the value of k_0/k_1 for the relay described as having a "strong ground-fault element."

The negative-sequence phase angle ($180+\phi_2$) depends on the impedance from the relay to the generators, including lines, transformers, and generators, and will probably range from 60 to 90 degrees. The zero-sequence phase angle ($180+\phi_0$) depends on the impedance from the relay to grounding points, including lines, transformers, and grounding impedance, and may range almost from 0 to 90 degrees. The positive-sequence phase angle depends on the negative- and zero-sequence phase angles at the fault, on the fault resistance, and on the line impedance from relay to fault. In the case of a 3-phase fault only the last 2 items come into play. A 3-phase fault near the relay, is, of course, a critical condition for the relay on account of the low voltage on all phases; hence the relay should be designed for maximum torque at a phase angle near the line impedance angle or somewhat more leading so that the arc resistance will have more effect.

Another critical condition for a polyphase directional relay is a single line-to-ground fault in which the fault current is limited by fault resistance or by system grounding impedance to a value comparable with normal load current; because the positive-sequence power flow during fault conditions is determined not only by the fault current but also by the normal load current; and for this reason it is possible for a directional relay actuated by positive-sequence power at the receiving end of a faulted line to give the wrong directional indication. This fact suggests the discarding of positive-sequence power for directional discrimination; however, it must be retained in order that the relay act during a 3-phase fault.

Having never seen a quantitative statement of the conditions under which load current may cause incorrect operation of a polyphase directional relay, I offer a criterion which is admittedly crude. It is

Figure 1

assumed that the power system beyond each end of the protected line may be represented by an equivalent electromotive force in series with an equivalent impedance. In figure 1, *F* represents the point of fault, *R* the relay location, *A* and *D* the equivalent electromotive forces, Z_A and Z_D the equivalent impedances, and Z_L the line impedance. Figure 2 is an approximate vector diagram

of positive-sequence voltages. AG and DG are the equivalent electromotive forces at the sending and receiving ends, respectively, and are assumed to be unaltered by the presence of a fault. F_1G is the voltage at the point of fault before occurrence of the fault and R_1G is the voltage at the relay under the same conditions. F_2G and R_2G represent the voltages at the same points during a mild fault, and F_3G and R_3G the same during a more severe fault. AF_1R_1D is a straight line on the assumption that

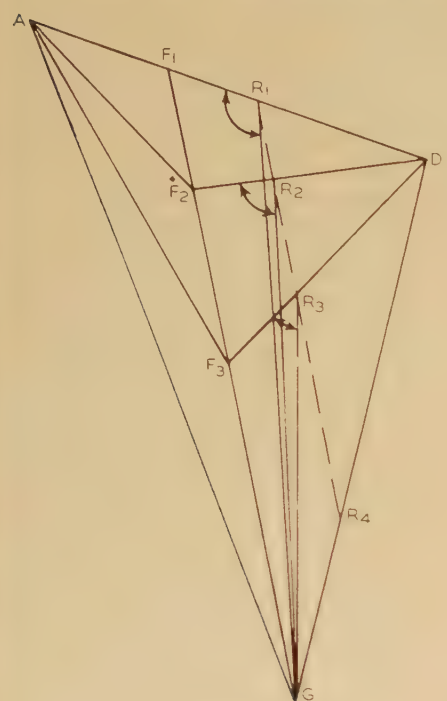


Figure 2

impedances Z_A, Z_L, and Z_D have the same angle. $F_1F_2F_3G$ is a straight line on the assumption that the positive-, negative-, and zero-sequence impedances of the system have the same angle. F_1R_1, F_2R_2, and F_3R_3 are the respective positive-sequence line drops from the fault to the relay, and the positive-sequence line currents are proportional to them and lag behind them by angle λ. The positive-sequence torque on relay R is proportional to $E_1I_1 \cos(\phi_1 + \theta_1) = R_1GXR_1FX \cos(\angle GRF + \lambda + \theta_1)$. If we assume for simplicity that the relay has maximum torque at an angle equal to the line impedance angle (i.e., $\theta_1 = -\lambda$), the torque is proportional to $R_1GXR_1FX \cos \angle GRF$. Angle GRF has value GR_1F_1 with no fault present, GR_2F_2 or GR_3F_3 for faults of increasing severity, and finally GR_4G or zero angle for a dead 3-phase fault. The relay torque changes sign when angle GRF passes through 90 degrees. This occurs when the reduction F_1F_2 in positive-sequence voltage at the point of fault is about equal to the arithmetical voltage drop from F to D under normal load conditions. If the latter does not exceed 20 per cent, any fault except a line-to-ground fault would give sufficient reduction in voltage to give a relay torque in the correct direction; and a line-to-ground fault would probably do likewise unless the fault current were limited by fault resistance or system grounding impedance. Although several assumptions have been made that are not strictly correct, it appears reasonably certain that a line-to-line fault will always give correct operation. This conclusion has been reached on the basis of the positive-sequence torque alone. The negative-sequence power provides an additional torque acting in the right direction.

Notation

The notation used in this discussion is like that in the paper with the following additions:

$I_A = I_c - I_b$
$I_B = I_a - I_c$
$I_C = I_b - I_a$

I_A, I_B, I_C will be called "delta currents," and may be obtained by a delta connection of the secondary windings of the current transformers.

ϕ = angle by which the current of a single relay element lags behind the voltage of same element.

ϕ_0 = angle by which I_0 lags E_0.

$-\theta$ = value of ϕ at which relay has maximum torque.

$-\theta_0$, $-\theta_1$, $-\theta_2$ = values of ϕ_0, ϕ_1, ϕ_2, respectively, at which relay has maximum torque.

λ = angle of line impedance.

k, k_0, k_1, k_2 = constants in torque equations.

W. R. Brownlee (Tennessee Electric Power Company, Chattanooga): The author has chosen a very clear method of indicating the performance of the new polyphase relay in terms of fundamental system impedances. The low energy requirements and small inertia of moving parts are a most welcome contribution toward accurate high-speed relaying.

The difference of 30 degrees in phase angle between a 3-phase fault and a dead single phase-to-phase fault is indeed an advantage. In addition to the fact that a single-phase line-to-line short circuit causes a phase angle difference depending on the impedance back to and including the generator, this same system and generator impedance is available to produce voltage at the relay terminals considerably in excess of the voltage on the faulted phase at the relay. This method of securing positive directional action for single-phase short circuits has been used in the connections of various impedance relays, usually 3 single-phase units.

One of the chief uses for the new relay element should be the 3-phase directional element combined with a voltage restraint element to provide a directional fault detector. The need for such a device with greatly improved accuracy and speed has been felt for many years, particularly in connection with lines and systems where the short-circuit current under certain generating conditions may be actually less than load current under other conditions. In order to meet this requirement a fault detector should have a nonlinear characteristic so that the current required to operate the unit varies with the voltage at some power higher than the first. Such a fault detector was incorporated as early as 1930 in the Brown Boveri reactance type relay. Shortly thereafter the General Electric Company placed in service a single phase *directional* fault detector incorporated in their type *GAX* reactance relay using voltage amplification by means of a circuit which was made resonant at low voltages only, by the application of a "thyrite" resistor. This equipment produced a characteristic curve of operating current versus voltage which was most highly useful in solving applications of high load current and low short circuit current.

It appears from the final equations that the new relay if provided with a voltage restraining element would have a straight line characteristic of operating current against voltage (for a balanced 3-phase condition) and even if the sensitivity has been increased it is disappointing that the nonlinear characteristic curve was not applied to the new relay. Perhaps further developments will make it possible to secure such a characteristic with the new relay without adding too much complication or expense.

This criticism is by no means intended to minimize the unquestionable achievement of the G. E. Company in developing the new cup type relay but to point out that the operating man is in urgent need of a much better directional fault detector relay than has been available in the past for taking care of 3-phase short circuits on transmission lines.

A. J. McConnell: Mr. Neher is correct in stating that with directional connections as in figure 2 and with a voltage restraining element connected to measure a value proportional to the area of the voltage triangle, the maximum range of the relay for a phase-to-phase fault is 50 per cent of that for a 3-phase fault. If the relay is designed to have the desired range for a phase-to-phase fault, it is sure to operate on a 3-phase fault at the same location. The limiting factor is that the greater reach on the 3-phase condition must not cause operation during normal load conditions.

The starting unit of the *GAX* reactance relay mentioned by Mr. Brownlee had a nonlinear characteristic principally in order to increase the torque and speed at low voltage without overheating at normal voltage. The author believes that such expedients are seldom necessary with the induction cylinder relay because of the high torque level and low inertia.

The first system described by Mr. Gerell is definitely one in which single-phase directional relays are likely to operate incorrectly. Zero-phase-sequence currents may be present with no positive and negative, in which case the line currents will be equal and in phase, and consequently, the indicated direction of at least one of single-phase relays must be incorrect.

As Mr. Gerell pointed out, the polyphase relay would solve the problem. When supplied with delta voltages or currents, the polyphase relay is not influenced by zero-phase-sequence quantities. This suggests another solution, namely, eliminating the zero-phase-sequence currents from the single-phase relays by delta connection of current transformers. Since a ground directional relay would then be necessary, the delta currents would have to be obtained by means of auxiliary wye-delta current transformers. The polyphase relay would

also require a ground directional relay, but no auxiliary current transformers would be required.

The use of wye-delta current transformer is equivalent to the second system mentioned by Mr. Gerell. The probable reason why no incorrect operations have been recorded on this system is because the zero-phase-sequence currents are eliminated from the relays by the wye-delta power transformers.

Mr. Kimbark's extension of the analysis of polyphase directional relay torques to include other connections is a valuable addition to the paper.

Another interesting extension is to consider the relay torques when the currents, voltages, or both are obtained from the delta side of a wye-delta transformer bank, the fault being on the wye side.

Equation 16 is one of many interesting combinations which can be derived from equations 4 to 15 inclusive by substitution of one or more of the following equations:

$$I_A + I_B + I_C = 0$$
$$I_a + I_b + I_c + I_g = 0$$
$$E_A + E_B + E_C = 0$$
$$E_a + E_b + E_c + E_g = 0$$

where E_g and I_g are residual voltage and current, respectively.

Referring to the term "strong ground element" a value of 4 has been used for k_0/k_1. It should be noted here that when this ratio has not been sufficient for the ground element to overcome the polyphase element because of load, the latter has been de-energized by means of a simple instantaneous overcurrent relay operated by ground current.

Mr. Kimbark's analysis of fault conditions when load is present is interesting. It has been usual to consider the ground element torque under fault conditions in comparison with polyphase element torque before the fault. This is conservative because the load torque during the fault is always reduced. Actually, this may be too conservative because the polyphase element also has a component of torque in the correct direction. However, if the assumed load torque is comparable with the fault torque, it is advisable to give the ground element complete control either as described in the previous paragraph or by employing a separate ground relay.

Operational Solution of A-C Machines

Discussion of a paper by A. R. Miller and W. S. Weil, Jr., published in the November 1936 issue, pages 1191–1200, and presented for oral discussion at the winter convention, New York, N. Y., January 27, 1937.

S. B. Crary (General Electric Company, Schenectady, N. Y.): The authors have shown quite conclusively that the operational methods of Park for analyzing the performance of synchronous machines, can be reasonably expected to check actual test results. Besides showing the nature of the phenomena such checks are valuable in creating confidence in this method.

The authors, in their equations, have used the per unit system presented in Park's paper "Synchronous Machines—An Extension of Blondel's Two Reaction Theory—I." When additional circuits besides the main field circuit are to be included, we have found that it is more convenient to express the equations with coefficients which are in terms of the armature circuit rather than their individual circuits. This makes possible the use of methods presented by T. M. Linville, "Starting Performance of Salient Pole Synchronous Motors," volume 49, AIEE JOURNAL, February 1930, pages 145–47. Furthermore, it reduces in half the number of mutual reactance coefficients required and makes it possible to draw simple equivalent circuits for the machine. This allows for a fair check of the calculations of the coefficients and, therefore, tends to reduce errors at this preliminary stage of the analysis.

A Suggested Rotor Flux Locus Concept of Single-Phase Induction Motor Operation

Discussion and author's closure of a paper by C. T. Button published in the March 1937 issue, pages 331–2.

Edward Bretch (The Advance Electric Company, St. Louis, Mo.): The method used by Mr. Button in his paper on the single-phase motor, that of considering the rotor flux as substantially constant along a fixed diameter of the rotor, enables one to clearly visualize the actions taking place in the single-phase squirrel-cage motor.

In the single-phase squirrel-cage rotor at and near synchronism, the following conditions prevail:

1. It carries the main flux produced by the primary.
2. The alternating primary magnetizing impulses are rectified with respect to the rotor through its synchronous motion.
3. The rotor flux is completely enclosed by low resistance rotor short circuits tending to hold it constant.

After the rotor flux is once established, the induced currents in the short-circuited rotor exert a strong tendency to hold this rotor flux constant and in a fixed relation to the rotor conductors. Consequently the rotor then reacts on the primary the same as if it was magnetized by a fixed magnetizing force across a diameter and by its synchronous motion carries this sustained flux around with it, establishing mechanically a true rotary field and tending to keep in synchronism.

A squirrel cage in a stationary or d-c field is commonly used to illustrate the principle of the polyphase squirrel-cage motor, the torque being developed by induced currents in the short-circuited rotor conductors as they cut across the magnetic field, utilizing what is commonly called the "speed" action. This same method can be used to illustrate the principle of the single-phase motor if we substitute a rectified single-phase a-c excitation for the d-c so that the primary excitation consists of a series of unidirectional impulses instead of a uniform unidirectional force as when excited by direct current.

This pulsating magnetizing force is the condition that prevails in the single-phase squirrel-cage rotor at synchronous speed, as the magnetic impulses produced by the single-phase exciting current are rectified with respect to the rotor, through the synchronous motion of the rotor, so that the rotor magnetism is produced through a series of unidirectional impulses. Consequently if we hold the rotor stationary and rectify the single-phase primary exciting current we will reproduce in a stationary rotor the conditions existing in the single-phase squirrel-cage rotor at synchronism.

In order to visualize what takes place in a squirrel-cage rotor, when running at synchronism in a single-phase field, let us assume a bipolar field with a single-phase winding capable of setting up a flux along the line *y—y*. Also let us assume the rotor has 2 individual short-circuited coils *A* at right angles to this flux and *B* in line with it.

Noting the positions of the coils with reference to the primary we see that *A* encloses the total flux, and is therefore in a transformer relation to the primary. Coil *B*, however, is in line with the flux and does not enclose it and consequently is not in the transformer relation to the primary. However, the conductors of coil *B* lie in the area of maximum flux density and in such a position that any motion of the rotor will cause them to cut across the field, thereby inducing local currents by the speed action, opposing motion and producing torque.

When the primary is excited by direct current no current will be induced in either coil as long as the rotor is at rest. Any motion of the rotor will induce currents in coil *B* by the speed action, opposing the motion and thereby producing torque. Coil *A* is in the neutral position with its conductors in the area of minimum or zero flux so that no current will be induced until the conductors move out of the neutral position and start cutting across the magnetic field. This is the polyphase condition.

If we now excite the primary with a rectified alternating current, to reproduce the single-phase rotor condition at synchronism, the magnetizing force will consist of a series of unidirectional impulses varying from

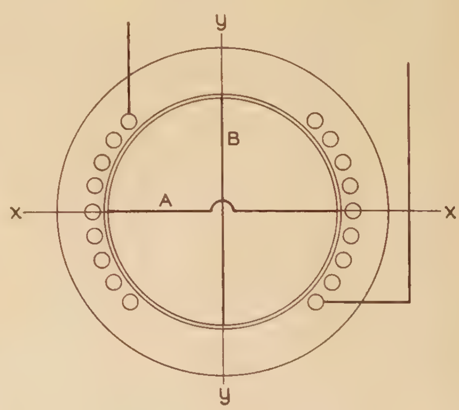


Figure 1

zero to a maximum. If it were not for coil A the flux would coincide with the primary current and vary unidirectionally from zero to maximum. However, due to the transformer relation of coil A any flux variation induces currents in the coil, opposing the flux change, so that when the primary magnetizing force decreases to zero, the flux does not, but is sustained between impulses by the induced currents in coil A. As the magnetizing impulses are unidirectional, the flux is unidirectional but varying in some degree with each impulse. The flux-sustaining currents induced in coil A complete a cycle with each impulse, and there being 2 impulses for each cycle of the primary rectified exciting current, the frequency of these flux-sustaining currents is double that of the primary current. The amount of flux variation through coil A between impulses depends upon its resistance. Theoretically with zero resistance the flux would be constant, and at the other limit, would coincide with the exciting current if the resistance was infinity. Both rotor resistance and magnetic leakage tend to decrease this sustained flux which is commonly called the cross flux.

With a substantially constant unidirectional flux established by the primary magnetizing impulses, stabilized by the double-frequency flux-sustaining currents in coil A, the opposition to the movement of coil B across the field, due to speed action, produces the torque the same as with d-c excitation.

To illustrate the location and nature of the single-phase rotor reactions, a rotor with 2 individual short-circuited coils at right angles was assumed. However, in the ordinary squirrel-cage rotor, under slip conditions, the conductors are constantly shifting from the position where the speed action produces torque to the position at right angles where the transformer action produces the double-frequency flux-sustaining currents and vice versa. As the rotor slips the frequency of the flux-sustaining currents will decrease in the same manner that the frequency of the slip or torque currents increase. Thus in the single-phase squirrel-cage rotor there are superimposed 2 sets of induced currents at right angles. The one is the torque or slip currents, in the area of the maximum flux, produced by the speed action, with a frequency proportional to the slip, becoming zero at synchronism. The other is the flux-sustaining currents in the area of minimum flux density, produced by the transformer action, with a frequency of double the primary frequency less the slip and proportional to the primary exciting current.

This method of treatment indicates that the double-frequency flux-sustaining currents, proportional to the exciting current, flowing in the rotor at synchronism, although they incur an I^2R loss, are produced through a transformer action at right angles to the torque currents, and thus do not act as a brake load and do not increase slip. It also indicates that the flux will not be as well maintained as slip increases due to the imperfect rectification of the primary magnetizing impulses as slip increases. The effectiveness of the rectification decreases with slip and when slip reaches 100 per cent, or with the rotor at standstill there is no rectification at all and consequently no torque producing condition.

In the polyphase motor, rotor resistance does not reduce the magnitude of the maximum, or breakdown torque, but merely lowers the speed at which it is developed.

In the single-phase motor we see that rotor resistance not only lowers the speed at which the maximum torque is developed, but through restriction of the double-frequency flux-sustaining currents and imperfect rectification of the magnetic impulses, the maximum torque is greatly reduced, as the speed at which it is developed is lowered. This explains the characteristic of single-phase motors that they must operate at less slip than polyphase motors for efficient operation.

It also indicates that high reluctance means high double-frequency rotor currents involving high rotor I^2R losses, irrespective of load, and thus the desirability of both low magnetic reluctance and low rotor resistance for efficient operation under running conditions.

While the single-phase squirrel-cage motor is a rotary field motor, it is in reality not a special case of a polyphase motor since the rotary field is not produced in the primary by the combined action of polyphase currents, but is produced in the secondary from an intermittent or single-phase primary excitation, through the sustained rotor flux, mechanically rotated by the motion of the rotor. This direct method of analysis by assuming single-phase conditions as they really are, rather than the indirect method of assuming special polyphase conditions which are more or less a mathematical fiction, seems to afford a much clearer insight into the interrelations of the various factors involved in the single-phase squirrel-cage motor.

C. T. Button: The comments by Mr. Bretch on the "Rotor Flux Concept of Single-Phase Induction-Motor Operation" (March 1937 issue) are very interesting. I do not interpret these comments as indicating that Mr. Bretch cannot agree with any part of the original paper; but he is apparently merely advancing some thoughts prompted by reading the paper.

It is felt that one should be as precise as possible; and particularly premises should be accurately stated lest they lead to increasing divergence from actual conditions as conclusions are developed.

At the outset of the discussion, then, we would not say that the theory "considers the rotor flux as substantially constant along a fixed diameter." The statement just quoted evidently refers to the condition at synchronous speed only and should so indicate. Also, the statement neglects the pulsating component in the quadrature rotor axis (plane of coil A in Mr. Bretch's figure). This is important—lack of completeness and precision leads to failure to obtain an explanation of such things as the pulsating torque component, negative torque existing at synchronous speed, etc.

The statement that "the primary magnetizing impulses are rectified with respect to the rotor through its synchronous motion" is an interesting way of expressing the situation, but is also lacking in the same way in conveying an accurate mental picture. Figure 2 of the paper is a picture that it is difficult to convey in a few words.

The paragraph by Mr. Bretch beginning with "after the rotor flux is once established" seems to be rather foggy and not to contribute anything omitted from the original paper. The concluding expression "and tending to keep in synchronism" is misleading. At synchronism the torque is negative and hence the tendency is to drop below synchronous speed.

Again, "if we hold the rotor stationary and rectify the single-phase primary exciting current," we will not "reproduce in a stationary rotor the conditions existing — at synchronism." There is a pulsating torque at synchronous speed, with a net or average negative value. The primary object of the paper was to lead to a concept of conditions as they are, rather than as they might be represented by something else, which in the case of the suggestion mentioned, would be inaccurate.

As soon as one attempts to investigate currents in rotor "coil A" and "coil B" he finds himself involved to such an extent that the only way out is to set up the mathematical expressions for voltages or currents, and proceed by the cross-field analysis as developed by H. R. West. The trouble is that "coil A" is only in a purely "transformer" relation to the primary for a passing instant, and "coil B" is only out of the transformer (or in a pure "speed") relation for a transient instant. Discussion as to which coil produces the cross field, and what the phase relations are, is not within the intended scope of the paper.

Take the statement by Mr. Bretch, "Coil B by speed action induces local currents opposing motion and producing torque." True, negative torque is produced opposing motion. But this is not motor action. Well, then, coil B is to set up the cross field. But if so, how can it produce a field in the x—x axis in time quadrature with the main field, since coil B itself would lie in the x—x axis when the main flux is zero and the cross field is maximum?

The so-called "transformer" voltage and "speed" voltage are in reality fundamentally identical phenomena. A voltage may be said to be generated in coil A because of change in magnitude of flux through it; and a voltage is correspondingly generated in coil B because of change in direction of the primary flux with respect to it. If the primary flux is at one instant in the plane of coil B and the next instant at an angle α with respect to coil B, then the next flux at the second instant has a sine α component which has developed in the plane of coil A. Thus change in direction of flux in the neighborhood of the plane of coil B means a change in the component of this flux in the plane of coil A, or in other words a change in flux through coil B. This is also transformer action of course.

Thus both coil A and coil B as well as every conductor around the rotor periphery have voltages induced in them due to change of flux linking them, which is in turn due to change in both magnitude and direction of the total flux with respect to them. To select 2 sets of conductors one of which at a certain instant has zero voltage due to change in flux magnitude while the other set has zero voltage due to change in flux direction cannot in the opinion of the writer be used in a simple manner to arrive at a complete concept of the basic phenomena of the operation of the motor in question. The point is emphasized that, for the

purposes for which the paper was written, it seemed desirable to deal with total entities rather than any of their various possible components.

It is not necessary to proceed further through the comments submitted by Mr. Bretch with replies. The object of the paper was to present a simplified concept, and the comments do not seem to increase the clarity, accuracy, nor completeness of the theory; but rather seem to do the reverse.

Some of the remarks of Mr. Bretch, however, may inspire the derivation of further conclusions on the basis of the theory outlined in the paper—such as variation of torque with slip or with change in motor constants, and behavior of the cross field at various values of slip both below and above synchronous speed.

Dyadic Algebra Applied to 3-Phase Circuits

August 1936 issue, pages 876–82

Complex Vectors in 3-Phase Circuits

December 1936 issue, pages 1356–64

Author's closure of 2 papers by A. Pen-Tung Sah published in the August 1936 and December 1936 issues, and presented for oral discussion at the tensor analysis session of the winter convention, New York, N. Y., January 26, 1937.

A. P.-T. Sah: Before answering some of the specific points that have been raised regarding the author's 2 papers on dyadic algebra and complex vectors as applied to 3-phase circuits, a reiteration of the viewpoint of these papers is perhaps helpful. One of the chief objects of the papers is to apply the method of Gibbs to 3-phase circuit theory. Whether Gibbs's dyadics should be considered to be obsolescent or not is a matter of individual opinion. In fact, the appearance of such work as Lagally's "Vektor Rechnung" in 1928 and A. P. Wills's "Vector and Tensor Analysis" in 1931 and other more recent articles of a purely mathematical nature on the extension of Gibbs's ideas are probably sufficient to show that Gibbs's work is not going in the direction of the scrap pile.

All engineers will probably agree that new concepts and relations will be more easily understood and grasped by the practical men if they are given in concrete rather than abstract form. It is due to this fact that in the exposition of the set of equation 1 of the dyadic paper (page 876) the author has arbitrarily introduced the orthogonal unit vectors **i, j, k** in order to show that the triad numbers, e_a, e_b, e_c, and i_a, i_b, i_c may be considered as the orthogonal projections of 2 vectors and that the 9 z's a dyadic operator used to change one vector to another. It is true that if we choose, we can resort to matrix interpretation of this set of equations. Indeed, as pointed out by Gibbs-Wilson in their book, a dyadic may be considered as a square matrix with 9 coefficients and a row or column matrix as a vector. To give a geometrical interpretation to the set of equation 1 may appear to be "irrelevant" to a pure algebraist but certainly should not be without assistance to an applied mathematician. An analogy in this case will perhaps make the situation clearer to the electrical engineer.

In the days when complex numbers were first studied, they have been defined as a dual number with 2 components a and b and written as (a, b). The addition of 2 such numbers is then defined as $(a, b) + (c, d) = (a + c, b + d)$ while their multiplication as $(a, b)(c, d) = (ac - bd, bc + ad)$. If this is compared with the present universal notation $a + jb$ for (a, b) and the definition of the product through the relation $jj = -1$, so that $(a + jb)(c + jd) = (ac - bd) + j(bc + ad)$, it is evident that the introduction of the imaginary unit j has not only clarified the algebraic work but also made a geometrical interpretation of complex numbers possible. If J. Slepian should think that j is not irrelevant to the interpretation of complex numbers, probably he can also be persuaded to give proper value to the introduction of the unit vectors **i, j, k** in the present papers.

As an unbalanced 3-phase circuit is of necessity more complicated than a single-phase circuit, so are the computations and the representations. In view of the present difficulties encountered in the formulation of a satisfactory definition of power factor in an unbalanced 3-phase system, the fact that there is a definite though varying angle between the voltage and the current vectors even for an unbalanced system should be further studied to see if there is a way out of the present complications. Those who think that the elliptical representation of unbalanced 3-phase systems to be not so good may want to withhold their final pronouncement until such a study has been completed.

Slepian has also suggested that the definition of the scalar product between two complex vectors might be more attractively given as:

$$\mathbf{X} \cdot \mathbf{Y} = X_1{}^*Y_1 + X_2{}^*Y_2 + X_3{}^*Y_3$$

so that the 3 vectors **u, f, b** would become mutually perpendicular. The suggestion is interesting but has 2 defects. According to the suggestion the steady-state complex power in a 3-phase circuit would be $\mathbf{E} \cdot \mathbf{I}$ (or $\mathbf{I} \cdot \mathbf{E}$) instead of $\mathbf{E} \cdot \mathbf{I}^*$ (or $\mathbf{E}^* \cdot \mathbf{I}$) as given in the present paper. Since in single-phase circuits, complex power is either E^*I or I^*E and not EI, the unsuitability of such a suggestion when applied to electric circuit theory is at once apparent. The second drawback of such a definition lies in the fact that it invalidates the commutative law for scalar products. In other words $\mathbf{E} \cdot \mathbf{I}$ would not equal $\mathbf{I} \cdot \mathbf{E}$ unless both E and I be real. The attendant inconvenience to the failure of the commutative law for the scalar product lessens a large amount whatever attraction the suggestion may have in other respects.

Referring to the discussion by G. Calabrese on the formula of the force between 2 elements of current-carrying conductors, it should be emphasized that the currents therein given are currents in conductors oriented in a physically real space and should not be confused with the current vectors used by the author.

The author agrees with Irven Travis in that any simplification in actual calculation of networks will be due to symmetry of impedances. Hence, there will be a good deal of lost labor in the solution of completely unsymmetrical systems by the method of symmetrical components. The merit of the present scheme of solution lies in its systematized organization of the otherwise numerous equations. It is gratifying to note that Travis and his students have used matrices to represent Stokvis-Fortescue transformation. In this connection the author would like to call attention to the advantages of using the author's expressions 56, on page 1362, having a different scalar multiplier from Travis's expressions 3 and 4. These advantages have been pointed out in reference 5 of the paper on complex vectors.

C. E. Rose has correctly pointed out a typographical error in equation 28*d*, page 881. As given by Rose, the equation is still not right. This error together with 3 others, one of which had been mentioned by C. A. Havill in his letter to the editor (Electrical Engineering, page 1287, November 1936), were all noted in the printed paper but escaped [the author's] notice on the galley proof. They were communicated on August 17, 1936, to the editor who promised to correct them later. [**Editor's Note:** Complete corrections as supplied by the author were printed on the "errata" fly leaf of the 1936 Transactions in accordance with established practice.] In view of the fact that the correction has not yet appeared, they are here reported in order to save the readers some trouble. The corrections are as follows:

1. Page 877, equation 3: All the 9 dyads should be united by plus signs and the dyad z_{ab}**ik** should read z_{ab}**ij**.
2. Page 881, second column, line 10: The words "up" and "down" should read "down" and "up," respectively.
3. Page 881, equation 28*d:* All the double vertical lines should be single vertical lines to denote determinants and the j's in front of each determinant should be j^2.
4. Page 882, equation 31: A dot should appear between each one of the impedance dyadics and the current vectors.

Rose's opinion regarding the covariancy and the contravariancy of the impedance and the admittance, though correct, does not apply to the first paper, because the unit vectors used therein are all orthogonal and there is no distinction between covariant and contravariant measure-numbers. Hence the indices used therein have been lower ones even in case of the admittance. Further, as shown in the author's second paper and concurred to by J. Slepian in his discussion there are covariant and contravariant measure-numbers of the same vector and measure-numbers of various degree of covariancy and contravariancy for the same dyadic. It would be better to say that both the impedance and the admittance dyadic can be expressed in one of the four forms as shown by equation 52, page 1362.

The author wants to thank K. L. Wildes for giving the new method such a fair trial in teaching it to his students. At present the author must admit that the technique

of solving actual problems by such a method has not yet reached its best possible stage. Undoubtedly if more professors can be induced to teach the method to their students, the required technique would be improved rapidly.

As regards the merits of the present method when compared with that of symmetrical components in solving actual problems, a good deal depends on the background of the user and the unbalancing condition of the system. The author has made a side-by-side calculation of several problems using both the present method and that of symmetrical components. The results speak very eloquently for the present method because it requires shorter and fewer equations besides less numerical and algebraic work. This does not mean that symmetrical components should be superseded by the present method. It simply shows that the present method is a general one, including the symmetrical components as a special transformation. In fact when machinery problems are studied from the present viewpoint, the Blondel 2-reaction theory will also come under the present scheme as a simple orthogonal transformation of co-ordinate system.

A New Thermal Fuse for Network Protectors

Discussion and author's closure of a paper by L. A. Nettleton published in the October 1936 issue, pages 1096–9, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 27, 1937.

C. P. Xenis (Consolidated Edison Company of New York, Inc., New York, N. Y.): The thermal fuse described by Mr. Nettleton incorporates an interesting principle in fuse design. The heat is generated at one point of the fuse assembly, and the circuit is interrupted at another. By properly selecting and proportioning the metals and alloys at these two points he has been able to obtain a very desirable current-time characteristic with minimum heat dissipation.

The author of the paper gives some data on 2 types of "all copper" network switch fuses, in comparison with corresponding data for the thermal fuse. In this connection it may be well to point out, that extensive investigations and tests on "all copper" fuses for use in network switches have resulted in designs which possess current-time characteristics far superior to those of "all copper" fuses used heretofore in connection with network switches. The small volume of copper fused when the circuit is interrupted makes it possible to successfully enclose such fuses in small individual fireproof enclosures which confine the arc and thus protect persons who may happen to be standing close to the fuse at the instant of blowing. This advantage, coupled with the relative simplicity and low cost of "all copper" fuses are points well worth considering in comparing with other types of construction.

Experience in the operation of distribution systems points definitely to the desirability of increased fuse protection wherever large amounts of equipment and cable insulation are liable to be in contact with the overheated conductors and arcs resulting from electrical failures. The thermal fuse, and other types of fuse designs which will adequately protect insulation from high copper temperatures and properly interrupt heavy short circuits constitute developments which will find several useful applications in energy distribution.

F. E. Johnson, Jr. (New Orleans Public Service, Inc., New Orleans, La.): I am glad to note that network protector fuses are now available which "follow through" the thermal-time curve of the transformer they are designed to protect. Attention was called to the need of such a fuse in connection with the discussion of a previous paper ("Developments in Network Systems," Brosnan and Kelly, AIEE TRANSACTIONS, July 1929, page 975) wherein the requirements of an ideal fuse were given. It was brought out at that time that the ideal fuse curve would lie just below, but parallel to, the safe thermal-time curve of the transformer. Figure 3 of the present paper indicates that the shape of the new fuse curve is practically ideal.

There are one or 2 points, however, which I believe warrant further discussion. The first of these concerns the permissible loading curve for a 500-kva network transformer, as shown in figure 3. Very little is definitely known about the life of transformers under short time overloads, and as a consequence the manufacturers have been somewhat hesitant about supplying curves which give allowable safe operating times for definite overloads. At the present time, however, the AIEE transformer subcommittee on electrical machinery has issued a proposed curve on short-time permissible overloads of network transformers 500 kva and smaller ("Proposed Transformer Standards," J. E. Clem, ELECTRICAL ENGINEERING, January 1937, page 32). This curve is to serve as a guide for intentional daily overloading (longer portion of curve) or emergency accidental short circuits (less than 5 minutes duration). For purposes of comparison, I have repeated curves *A* and *B* of figure 3 of the author's paper and have drawn in the proposed AIEE curve.

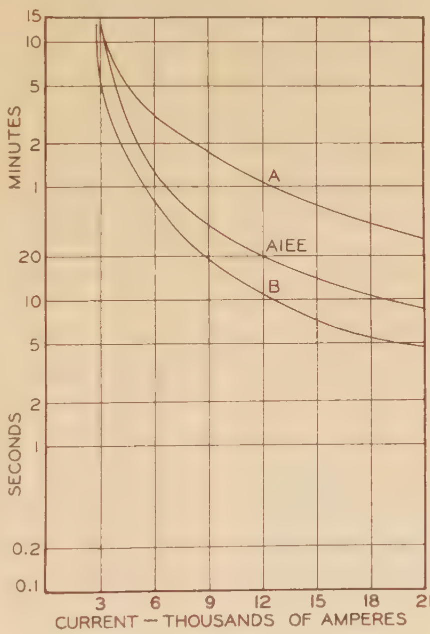


Figure 1

I have included the AIEE curve in order to draw attention to the need for standardization in applying the fuses to network transformer overload curves. In the present case, for instance, at 12,000 amperes the allowable overload time according to AIEE Standards is 20 seconds, while curve *A* gives a time of about 65 seconds, or over 3 times as long. Either the AIEE curve is very conservative or the operating company is willing to overload their transformers for higher final temperatures than was contemplated by the AIEE committee. Of course, in the present instance, the fuse would actually blow before the temperature set up by the AIEE curve was exceeded. In other applications, however, this might not be true. I would be interested in knowing what maximum copper temperatures were expected by Mr. Nettleton when curve *A* was drawn. If we apply the fuses on the basis of the AIEE curve in every instance, I believe that the transformer manufacturers would consider the action sufficiently conservative not to materially reduce the life of the transformer.

I would also like to ask Mr. Nettleton if fuses of this type have been developed for other sizes of network transformers.

J. S. Parsons (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): 1. The engineers of the Brooklyn Edison Company have, I feel, made a very important contribution to the art of fusing network protectors by developing the new low melting alloy fuse described by Mr. Nettleton. The Westinghouse company has been manufacturing fuses of this type for more than 2 years, first for the Brooklyn Edison Company and later for a considerable number of other companies operating low-votage a-c network systems.

2. The earlier fuses were built just as described by Mr. Nettleton and shown in figures 1 and 2 of his paper. Due primarily to manufacturing difficulties, however, some changes have since been made and others are now about to be made in this fuse.

3. As Mr. Nettleton has pointed out, the mounting ends of the fuse are bent at a slight angle from the mounting plane so as to prevent the possibility of the copper straps coming too close together or touching after the alloy has melted even though the mounting surfaces are poorly aligned. This construction puts the alloy slab under tension. To reduce this stress the copper strap portions of the fuse are now made of 2 or more copper laminations, depending upon the size of the fuse, instead of being made of a single heavy copper strap. The use of 4 laminations instead of a single copper strap reduces the stress on the alloy slab approximately 50 per cent. This reduces the possibility of the fuse opening mechanically due to the breaking of the bond between the copper and the alloy while in service. To guard against the possible mechanical opening of a fuse in service

because of the stress mentioned and those which may result from expansion and contraction of the protector, each fuse is given a tension test of 250 pounds. The failure rate under this test in production runs as high as 25 or 30 per cent failures due to the difficulty of getting a good bond between the copper and the cadmium-lead-tin eutectic alloy. Because of this we propose to change to the second alloy mentioned by Mr. Nettleton which is a eutectic mixture of lead and tin. It is very much easier to get a good bond between this alloy and the copper. A considerable number of these fuses have been built and tested at 1,000 pounds tension without a single case of failure. As a matter of interest, I might mention that one of these fuses, using the lead-tin eutectic alloy and having a minimum blowing current of about 2,800 amperes, was put under a continuous tensile stress of 500 pounds and tested for a week carrying 2,000 amperes for 8 hours and no current for 16 hours each day without being damaged. We are also considering the use of a $^1/_{16}$-inch diameter "nichrome" rivet through the alloy and copper to give an added factor of safety against mechanical failure.

4. The difficulties we have had with this low melting alloy fuse have all been mechanical and the changes mentioned should entirely eliminate them. The same current-time curve can be secured using the tin-lead eutectic alloy and the nichrome rivet as we have been getting with the cadmium-tin-lead eutectic alloy. The change in alloy will also have a negligible effect on the watts loss in the fuse. In this type of fuse only a small part of the total loss is in the alloy. For example, in the case of the fuse normally supplied on a 1,600-ampere protector only about 18 per cent of the loss is in the alloy. Mr. Nettleton has pointed out that the loss in this fuse is only about 25 per cent of that in the copper fuses the Brooklyn Edison Company previously used. The loss in the alloy fuse is also roughly only 50 per cent of the loss in the zinc fuse which we have supplied in the majority of our network protectors in the past. This fuse is also considerably shorter than the zinc fuse. Because of this, its improved current-time characteristics, and its decidedly lower loss we have used this low melting alloy fuse in our new type *CM*-22 heavy duty network protector. This fuse can also be used to replace the zinc or copper fuses supplied in most designs of our type *CM*-2 protector.

5. Since we adopted this fuse as standard on the type *CM*-22 protector I have been asked many times whether the gap which is left after the alloy melts is adequate to definitely open the circuit. We have naturally made a large number of interrupting tests on this type of fuse, and have successfully opened currents ranging in magnitude from the minimum blowing current of the fuse to 59,000 amperes root-mean-square with a recovery voltage across the blown fuse of approximately 208 volts. The normal gap between the outer end of the copper straps is $^1/_8$ inch, however, when the fuse blows on high values of current the magnetic forces bend the straps away from each other. After opening 59,000 amperes the gap between the outer end of the copper straps was about $^3/_4$ inch.

6. Mr. Nettleton mentions a critical current above which the fuse will blow in the bend of the copper strap. We found this critical point to be at 20,000 amperes root-mean-square on the fuse normally used on an 800-ampere protector, however, this critical point was not reached at 59,000 amperes root-mean-square on the fuse for a 1,600-ampere protector.

J. A. Brooks (Consolidated Edison Company of New York, Inc., New York, N. Y.): The last decade has seen a great increase in the extent of low-tension a-c networks. A great deal of time and effort has been expended in studying network requirements and in developing and improving network equipment. The automatic network protector has received a large share of this attention and has reached a high degree of perfection. In view of all this it is indeed surprising that so little has been accomplished toward improving the fuses used with network protectors.

As Mr. Nettleton stated in his paper, fuses were originally installed in series with network protectors to insure interrupting heavy back-feed currents from the network toward the primary feeder in cases where the network protector fails to trip. At that time the fuses were not regarded as essential for protecting the transformer against overloads and probably would not have been used at all if the network protector could have been trusted to operate correctly in every case of back-feed current.

The fuse originally used was the copper link fuse which was the only kind readily available. One disadvantage of this fuse is the high melting point which requires high losses in order to blow. At ordinary loads the losses are sufficiently high to reduce the rating of enclosed type network protectors. Another disadvantage is that the fuse operates too rapidly and often blows prematurely on short circuits in the network grid. On the other hand, it is possible to overheat and damage the transformer on currents that are not quite large enough to blow the fuse.

In recent years we are awakening to a realization of the dangerous overloading of equipment that may result from a partial shutdown of a network or that may occur when attempting to reenergize a dead network. Most improvements in network engineering are associated with actual operating experience. In the case of extremely rare but severe contingencies such as a partial or complete shutdown of a network area we cannot wait for experience to teach us the best procedure. Although we all hope to escape such a castastrophe as a network shutdown, it nevertheless is necessary to give careful consideration to plans for minimizing as far as possible the area affected, and for starting up the dead sections as promptly as possible. In view of the loss of capacity due to damage that may accompany a shutdown it is vitally important to be able to take advantage of available capacity up to the maximum permissible limit of loading.

The copper link fuse is a handicap to operation since its premature blowing on high currents may contribute toward shutting down networks and will hamper efforts to start up. At the same time the high minimum blowing current may permit the burning out of transformers and associated equipment. It would appear that "back up" protection is no longer the sole function of the fuse. The fuse is essential to provide overload protection and its characteristics should be such that it will only function as a last resort to prevent costly and embarrassing damage to equipment. When a satisfactory fuse is available to meet this requirement, a great advance will have been made. Such a fuse must be reasonably simple in construction, must have low losses, must be able to interrupt maximum currents, must be consistent in performance, must be stable under repeated heating and cooling, must be harmless to nearby workmen and must be available at a reasonable cost.

The use of a low melting point alloy in the fuse has inherent advantages in that the fuse operation becomes to a large extent dependent upon transformer and network-protector temperature. Starting cold at full load, for example, the fuse immediately takes a certain temperature rise above the network protector buses. The network-protector temperature rises more slowly, leveling off after 2 or 3 hours and after that increases at a very slow rate as the transformer and manhole warm up. A moderate overload that would blow the fuse in a few hours when the transformer and protector are already hot might require from one to 2 days when starting cold. On larger overloads the fuse blows without waiting for the other equipment to warm up but the time of operation will vary considerably according to the initial temperature of the equipment. In other words this type of fuse takes all possible advantage of any additional overload capacity that may be available.

The fuse described in Mr. Nettleton's paper meets most of the desirable requirements for a network protector fuse. Further development along this line may produce a fuse which comes even closer to meeting all the requirements.

L. A. Nettleton: The AIEE time-current curve for transformers, referred to by F. E. Johnson, Jr., shows the maximum duration of overloads that can be permitted without reducing the normal expected life. Curve *A* is based upon winding temperatures ranging from 125 degrees centigrade for 10 minutes up to 180 degrees centigrade for 25 seconds which will cause some deterioration and will probably shorten the life of the transformer to some extent.

The fuse must protect not only the transformer but also the network protector and connected cableleads. The network protector and leads have less thermal capacity than the transformer and may overheat first on overloads. The new fuse operates in sufficiently short time to be sure of protecting the network protector and leads in addition to the transformer.

Low losses are important for fuses used with enclosed network protectors, but where the protectors are not enclosed the losses are unimportant. Copper fuses require high losses to attain the necessary high fusing temperature. A design of copper fuse having a suitable time temperature characteristic, as mentioned by C. P. Xenis, should be satisfactory for use with nonenclosed protectors.

There is a wide variation in the permis-

sible overload that the transformer and associated equipment can withstand, depending upon the initial temperature. The fusible alloy used in the new fuse melts at such a low temperature (about 145 degrees centigrade) that the fuse operation is strongly influenced by the temperature of the network protector buses to which it is bolted. The fuse will, therefore, allow much greater overloading when the network protector is cold as compared to conditions where the protector is hot. Substitution of a metal or alloy having a higher melting temperature will reduce the ability of the fuse to distinguish between high and low initial temperatures of the equipment.

This fuse was developed for use with 500-kva network units which are used almost exclusively in Brooklyn. It can, however, be readily adapted to other ratings by changing the thickness of the copper straps.

This fuse meets most of the desired features enumerated by J. A. Brooks, the principal difficulty being the mechanical weakness discussed by J. S. Parsons, which results in an occasional fuse breaking open sometime after installation. However, it should be possible to correct this difficulty after further development.

A New Service Restorer

Discussion of a paper by E. F. Sixtus and W. R. Nodder published in the January 1937 issue, pages 180–2, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 27, 1937.

D. C. Prince (General Electric Company, Philadelphia, Pa.): The service restorer described by Messrs. Sixtus and Nodder should prove effective in improving service on lightly loaded lines to a considerable extent. It would appear that it gives somewhat the same performance as a repeater fuse but, of course, has the advantage of being totally enclosed and consequently better protected from the weather. It has in common with the fuse a property of operating a total of only 3 or 4 times before it must be serviced, although at such service intervals the only expense may be that entailed in sending a line man to its location.

Both the "service restorer" and the repeater fuse are open to the objection that they represent an unknown hazard to service. When they are first installed, or immediately after having been serviced, they can ordinarily be depended upon to open and reclose in the event of a temporary fault. However, after any storm there will immediately be a question as to the condition of all such devices; how many will have operated, how many will have operated more than once, which installations require immediate attention, and which require no attention at all. For these reasons, it seems as though the specifications outlined in the 7 points of the paper should be amplified somewhat, as:

8. The device after having reclosed any number of times short of the complete cycle to lock out should reset itself in a relatively short time to its original condition.

9. In the event of a persisting fault, the device should lock out after the complete cycle of trips and reclosures and then require manual reclosure after the fault has been removed.

10. The device should require no servicing until after lock out caused by a persisting fault and then it should require only manual reclosing after the cause of the fault has been removed; or in case of no lock out if should require servicing only at infrequent intervals, such as 6 months to a year.

On oil circuit breakers immediate reclosure serves a very useful purpose because from 75 per cent to 90 per cent of faults are of the nonpersisting type and are cleared after a single trip and reclosure. On the small service restorer, or oil circuit recloser, this feature is not so important, providing the reclosing time is relatively short, in fact a small time delay may often be beneficial.

Specification number 6 is not universally applicable. A very large fraction of all distribution lines serves single phase lighting and motor circuits. For such service, single-pole devices in the single-phase branches afford adequate protection. A triple-pole device in the 3-phase line would, in case of a persisting fault, unnecessarily interrupt service on some of the single-phase branches not in trouble.

In designing the *FP*-19 recloser, the possibilities of spring and weight operation as well as local battery were considered. As pointed out, the use of short circuit current is obviously the most attractive, but was discarded by the authors because they saw no way of securing a low enough trip current. The recloser, however, does operate at a sufficiently low tripping current without either the complication or cost of the alternative arrangements. There are doubtless applications for which a 3-pole device is essential and in which the limitation of 3 or 4 operations only between servicing will not be a prohibitive objection, for which applications the "service restorer" should prove of value.

Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines

Discussion and authors' closure of a paper by Philip Sporn and D. C. Prince published in the January 1937 issue, pages 81–90, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 27, 1937.

I. W. Gross: See discussion, page 1038.

T. G. LeClair (Commonwealth Edison Company, Chicago, Ill.): The paper by Messrs. Sporn and Prince is very timely, because it describes a new and important step in the art of furnishing greater reliability of service for transmission systems. The practical development of 6-cycle circuit breakers and one-cycle relays has made possible this forward step, the prevention of service interruptions on a single-circuit, high-voltage transmission line. The laboratory and field tests indicate that the reclosing mechanism is satisfactory and that the new device can be expected to have a number of applications.

It is not possible, and the authors have not attempted to make a general statement that reclosing circuit breakers could be used to prevent service interruptions on all single-circuit transmission lines. It is indicated that, with reasonable development, commercial circuit breakers can be made which will reclose within the minimum time allowable to prevent undue risk of restriking an arc on the transmission line. The question of whether or not this time will be short enough to prevent service interruption is a function of the system conditions rather than a function of the characteristics of the relays and circuit breakers. To know whether this principle can be applied, the important question is whether or not during the momentary interruption of the circuit the rate of acceleration of equipment at the sending end of the line and the rate of deceleration at the receiving end of the line will be too rapid to avoid instability.

On a system such as the one where the tests were made, the interconnection is between 2 large generating systems, each with a capacity of over 1,000,000 kva. In this case the inertia in each of the 2 systems is such that the frequency of neither system will drift rapidly at the moment the interconnection is broken. Therefore, the chances of successful reclosure are appreciably greater than they would be if the 2 systems were only $^1/_{10}$ as large with the same power flow through the circuit under test.

An interesting example of the possibility of reclosing circuit breakers is the 132-kv interconnection from Powerton station to Waukegan station in Illinois. One circuit of this interconnection is supplied by a single, 50,000-kw generator and carries a load of 50,000 kw distributed over more than 200 miles of circuit. A set of reclosing circuit breakers between the Powerton generator and the next adjacent load would be useless to prevent service interruptions, because the Powerton genertor would accelerate too rapidly when its full load was suddenly interrupted. However, a reclosing circuit breaker near the Waukegan end of the long transmission system could be used very effectively to prevent service interruption, because the load on the circuit between Powerton and Waukegon is great enough to prevent the Powerton and Waukegan systems from drifting apart rapidly.

This reclosing scheme could also be used very effectively to improve service to relatively small important loads carried from a high-voltage interconnected system. By the use of reclosing circuit breakers on a branch line with a single circuit, it should be possible to maintain a standard of service very nearly equal to that to be obtained on the orthodox double-circuit tower line.

A. C. Schwager (Pacific Electric Mfg. Corporation, San Francisco, Calif.): The authors are to be commended for contributing valuable information on a subject which promises to become of major importance in the improvement of continuity to service on transmission lines. The field as well as laboratory tests reported show that a large percentage of arc-overs on lines can be cleared by means of an extremely short service interruption.

It is interesting to note that the special reclosing mechanism is of the spring actu-

ated type, the authors apparently realizing that the conventional solenoid control is not feasible for application to such high speeds.

The restriction of the opening stroke to 8 inches appears to be a serious limitation to the general application of this mechanism.

Although the arc length during all the tests was of 7 inches or less cases will have to be anticipated where longer arc lengths must be expected. Reference is made to an AIEE paper by Messrs. Spurck and Skeet, "Circuit Breaker Field Tests on Standard and Oil-Blast Explosion-Chamber Oil Circuit Breakers," figure 9 of which shows that on a different 132-kv system arc lengths of 14.5 inches were recorded. It would be interesting to know if reclosing in this case could be accomplished without a radical change in mechanism design and without increase in the reclosing time.

The company with which the writer is associated has also designed and built a motor-operated spring-actuated mechanism suitable for ultrahigh-speed reclosing. This mechanism gives full initial opening stroke to the blades with a de-energized interval of 17 cycles. A 69-kv breaker equipped with this mechanism is in service since February 1936, a 115-kv installation having been recently completed. A paper is being prepared by the writer giving detail information on construction and field experience.

R. D. Evans (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): 1. The authors are to be commended for their work in obtaining operating experience on high-speed reclosing breakers. Of particular value is the data on the time necessary to avoid fault re-establishment upon circuit re-energization.

2. The problem of maintaining service continuity on systems with synchronous machines (or the stability problem) has been

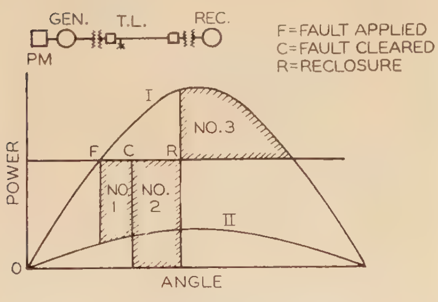


Figure 1. Power-angle diagram for reclosure; single-circuit case

I—Curve for normal circuit
II—Curve for fault condition (2L-G)
For stability, areas (1 plus 2) < area 3

one of particular interest to me. A number of years ago some of my associates and I proposed the high-speed clearing of faults as a means of improving system stability. This proposal was followed almost immediately by one to use high-speed reclosure to improve stability. U.S. Patent 1,899,613, filed in 1929, employed high-speed reclosure at high voltage and a superposed frequency relay scheme to obtain high-speed simultaneously opening of circuit breakers. Considerable development has been required to bring these schemes to commercial use, and the high-speed fault clearing scheme being simpler came into use first. As a part of the general investigation of high-speed reclosure, work was carried out by Messrs. Griscom and Torok, as mentioned by the authors, in order to determine the de-energizing time necessary to prevent re-establishing the arc.

3. The paper does not discuss the stability features of the problem, that is, the

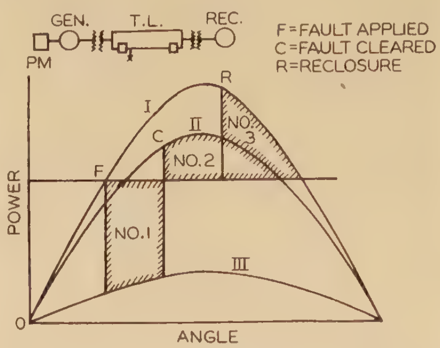


Figure 2. Power-angle diagram for reclosure; 2-circuit case

I—Curve for 2 lines (normal)
II—Curve for one line (normal)
III—Curve for fault (2L-G)
For stability, area 1 < (areas 2 plus 3)

relation between the fault clearing and reclosure time to the amount of load that can be carried with stability. For this reason 2 illustrations have been prepared to discuss this phase of the problem in general terms. Figure 1 assumes a simple system in which power is transmitted from a generator over a single-circuit transmission line. The line is assumed to be subjected to a fault requiring isolation to suppress the arc. This is followed by reclosure to improve stability. The power-angle diagrams for the different conditions from the application of the fault to the subsequent reclosure are shown in the figure. Stability will be secured if the sum of areas number 1 and number 2 is less than area number 3. It is of some interest to point out that for 2 breakers with equal reclosing time without arc re-establishment, the one with the slower fault clearing time will be more favorable from the stability standpoint.

4. High-speed reclosure is also applicable to improve the stability of two-circuit transmission systems illustrated in figure 2. The power-angle diagrams for this case are somewhat different than for the single-circuit case of figure 1. In this case stability will be secured if area number 1 is less than the sum of areas number 2 and number 3. The size of area number 3 is a measure of the advantage secured by high-speed reclosure.

5. In connection with the application of reclosing breakers to either single-circuit or double-circuit systems, considerable improvement in stability will be secured if the sending-end machines are not greatly unloaded during the fault condition. Hence, artificial means for loading the sending end may prove valuable in combination with reclosing circuit breakers. Such artificial loading may be obtained by the "stabilizing" resistors, the use of neutral resistors, and other measures. Such a combination may avoid the necessity for unduly high speed in reclosing breakers and make possible the use of simpler tripping mechanism than would be feasible otherwise, thus reducing first cost and maintenance expense which are obviously desirable.

V. M. Marquis (American Gas and Electric Company, New York, N. Y.): Ultrahigh-speed reclosing of high-voltage transmission lines places the transmission system, and especially important tie lines between systems or sections of systems, in an entirely new light. It is only necessary to consider that ultrahigh-speed reclosing allows a line to trip out and reclose without losing synchronism between systems in order to realize the field which is opened up by the development of this equipment.

Many important developments have been made for combating lightning on transmission lines but all cases of trouble do not result from lightning, so that even if the lightning problem were solved, there would still be cases where transmission line faults would cause interruptions. Ultrahigh-speed reclosing, however, offers a definite possibility for insuring substantially continuous service of lines on which it is applied.

After the successful results with the ultrahigh-speed reclosing on the Fort Wayne-Marion line, described in the paper, studies were made with reference to the application of ultrahigh-speed reclosing to the Twin Branch-Fort Wayne line. Figure 3 shows this line which is part of the Ohio-Indiana high-voltage transmission system of the American Gas and Electric Company. This line between Howard and Twin Branch forms a very important tie and it is essential that its continuity of service be maintained. The large interconnected system, of which the section shown is a part, normally has some 7,000,000 kilowatts of capacity in service; of this, approximately 2,000,000 kw of capacity is west of Fort Wayne and 5,000,000 east of Fort Wayne.

At the time this study was started, this double-circuit line had only one circuit installed, and calculations were made to determine the speed of reclosing required for various amounts of load transmitted over this tie line. With the present single circuit, it is possible to carry about 100,000 kilowatts over this line and maintain proper voltage. The calculations indicated that it would be possible to deliver this amount of power if the total time of separation was kept to about 30 cycles. The calculated curve showed that this amount of power could be increased to approximately 140,000 kw for a 12-cycle total time of separation and to approximately 160,000 kw for a 6-cycle total time of separation.

In general it can be stated that for single-circuit operation, the amount of power that can be carried through a disturbance with rapid reclosure of the faulted circuit increases appreciably as the time of separation between the systems is decreased. This, of course, indicates the desirability of keeping the fault and reclosing time to a minimum even though the systems are large.

Since these first studies were made, it has

been decided to double-circuit this line and further checks were made to determine the advisability of ultrahigh-speed reclosing for both circuits. This showed that, with double-circuit operation, rapid reclosing for faults on one of the circuits would make it possible to transmit appreciably more power by reclosing the faulted circuit than if this circuit were not reclosed. In general, it can be said that the gain to be realized by successful reclosing of the faulted circuit increases with the increase in the distances between high-tension bussing stations and also with the increase in size of the 2 systems to be interconnected. In this case, however, it is obvious that the speed of reclosing of the second circuit is not critical. For double-circuit faults, rapid reclosing on both circuits is particularly advantageous and in general to obtain full benefits in connection with a double-circuit line, both circuits should have ultrahigh-speed reclosing.

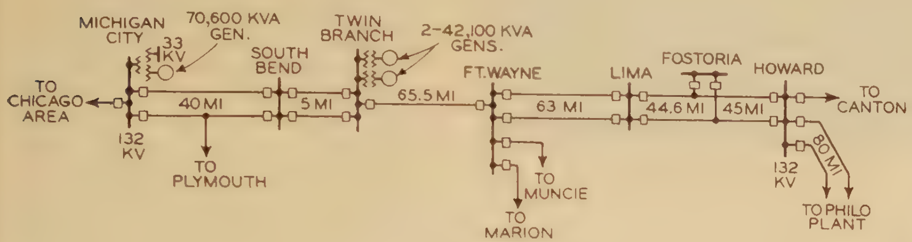


Figure 3

There still remains one unknown in connection with reclosing a faulted transmission circuit and that is the question whether the arc would be sufficiently deionized that it will not restrike when the circuit is reclosed. This has to be considered in connection with reclosing the faulted circuit of a double-circuit line, for if the faulted circuit is reclosed and the arc restrikes when reclosed, then the system would be disturbed more than if this circuit had not been reclosed.

In the case cited, the systems on either side of the tie line in question are very large and have correspondingly high inertias. Cases involving a single hydro plant connected to a large steam system or even a small steam plant or system connected to a larger system will require much faster reclosing. However, even in this case there is a possibility that upon reclosing, the smaller plant or system will pull into step. Each case should, of course, be carefully analyzed to definitely determine the gain to be realized in using ultrahigh-speed reclosing. This analysis should not only determine if the systems will lose synchronism but also determine, if synchronism is lost, whether synchronism can be quickly regained without undue disturbance to the systems if reclosed—that is, there may be some cases where there is a definite advantage in reclosing even though synchronism is momentarily lost.

Ultrahigh-speed reclosing seems to offer such large gains that its application should be seriously considered on all high-tension lines where their continuity of service is a major factor in the operation of the system. There are obviously still some unknown quantities in connection with the application of ultrahigh-speed reclosing. It is hoped that others will help in thoroughly investigating their unknowns to make this new tool in the art of transmission a thoroughly reliable one.

J. B. MacNeill (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): High-speed reclosing is a natural corollary to high-speed circuit interruption. The reduced arc energy and depreciation of contacts and oil associated with modern interrupters makes it feasible to restore service without waiting for the circuit breaker to vent gases and establish dielectric strength.

To illustrate the growth of reclosing service, reference is made to data presented to the electrical equipment committee of the Edison Electric Institute for the year 1935 covering 3,680 reclosing operations on all voltage classes from 2.3 kv to 110 kv. First reclosure was successful in 78 per cent of these cases, subsequent reclosure was successful in 10 per cent, and there remained 12 per cent of lockouts.

The paper by Griscom and Torok in the *Electric Journal* for May 1933 gave at this relatively early date a good approximation of the limitations imposed by deionization of the arc stream upon the possible speed of reclosure. Other contributions have since been made, and there appeared in ELECTRICAL ENGINEERING for October 1936 an interesting paper by Pearce, Powers, Stewart, and Heberlein covering the application of carrier relaying and rapid reclosing of a 110-kv line which acted both as a trunk interconnection and a load feeder. The paper now under discussion by Messrs. Sporn and Prince adds considerably to our knowledge of the subject.

The method and apparatus used for securing high-speed reclosure by the authors is novel. By means of a very powerful duplex operating mechanism they were able to get reclosure in 16 cycles from the time the tripping impulse was given; but to secure this time the breaker was permitted to open only 8 inches. This is only a fraction of the normal travel of a circuit breaker for 138-kv service, and it would seem encroaches definitely on factors of safety for circuit interruption. There is no assurance that all types of short circuit can be ruptured at this voltage and under all operating conditions with an 8-inch stroke.

The writers summarize by stating:

"If reclosing is to be at a long enough interval to give little probability of a restrike, voltage must not be applied to the line for about 12 cycles after the arc has been interrupted. With an 8-cycle breaker this gives 20 cycles for the over-all reclosure time At the other extreme, reclosure after $2^1/_2$ cycles will be successful sometimes. If a flashover is caused by multiple lightning strokes, some reclosures longer than 20 cycles over-all may well be followed by restriking. For that reason the final limits will not have been determined until after a considerable period of experience under actual service conditions."

Since this appears to be the case, then we should investigate carefully to see if the necessary reclosing functions cannot be obtained at moderate expense and with relatively simple mechanisms. Admittedly the mechanism used by the authors is very expensive and complicated and will possibly be difficult to maintain in satisfactory operating condition.

As an illustration of what can be accomplished by relatively simple means, figure 4 shows the operating mechanism on a 3-pole 115-kv circuit breaker of large capacity normally operated from a battery, but on a recent job furnished with a "rectox" built into the mechanism for operation from an a-c source. This mechanism is practically a standard solenoid of simple and sturdy construction arranged with some features to adapt it to high-speed reclosure, such as improved relationships between the power requirements of the breaker and the physical efforts of the solenoid at different points of its stroke.

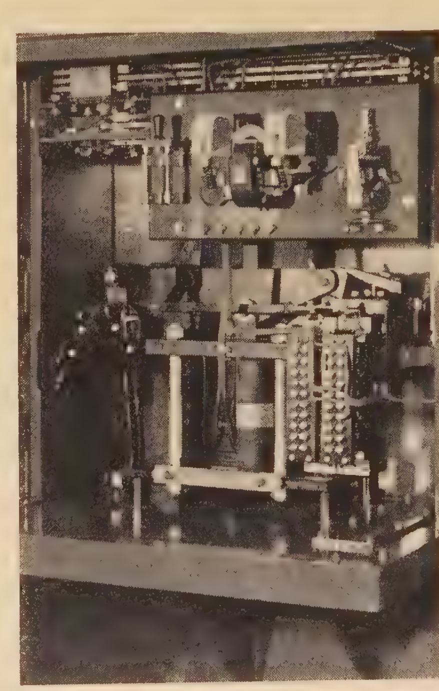


Figure 4

Figure 5 shows an oscillogram of the operation of this breaker consisting of tripping followed by reclosure, in which the breaker is permitted to reach a travel of 21 inches, or 75 per cent of its total stroke before reversing the downward movement of the contacts. This length of stroke obviously gives a large factor of safety for circuit interruption, and had this distance been encroached on to speed up the reclosing action, the time for opening and reclosing could have been materially reduced.

Of course, the high-voltage apparatus presents a more difficult problem than low

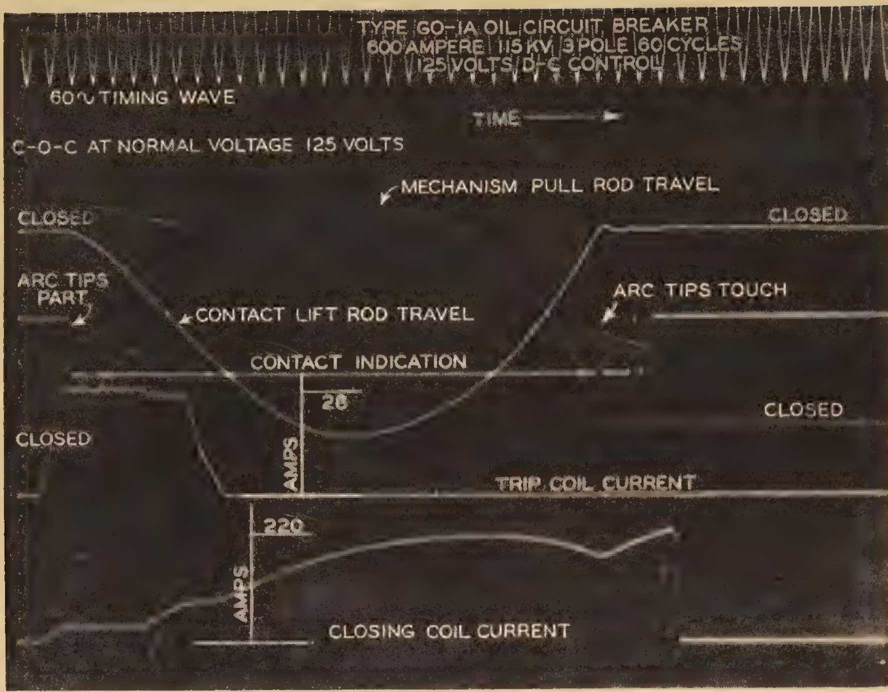


Figure 5

voltage, and the elapsed time for such voltages as 230 kv will be greater than on smaller devices. Considering, however, the nature of the elements involved and the necessity for having assurance of original fault deionization before reclosure is made, it seems wise to conclude that practically all reclosing requirements—at least at moderate voltages—can be taken care of with relatively simple and inexpensive mechanisms.

In discussing this subject it is well to remember that a reclosing time consists of two parts: first, the time to open the short circuit; and, second, the time to reclose the breaker. For a given total time consumed by the reclosing cycle, it is very desirable that a minimum amount be taken up by circuit rupture, leaving as large a share as possible available for reclosure. This division of the time will insure better circuit breaker action, less depreciation of line material and circuit breaker parts, and increased assurance that the original short will have been deionized at the time reclosure is complete.

E. E. George (Tennessee Electric Power Company, Chattanooga): From the standpoint of transmission companies, Sporn and Prince and their associates have apparently made one of the most important developments presented to the Institute in several years. Rapid reclosing of tie lines does not necessarily mean that one line will do all of the work of 2 lines heretofore, but it should mean that one line will do most of the work most of the time. The authors have actually accomplished and put in practice what some of us have only talked about. Differences of opinion about details should not detract from the luster of an outstanding accomplishment, so it may perhaps be pardonable to discuss the term "ultrahigh-speed" as applied to reclosing. The following definitions have been taken from the dictionary. "Ultra" means beyond familiar limits and indicates ordinarily something of microscopic or astronomical dimensions.

"Immediate" means consecutive, "instantaneous" means as fast as possible—with no intentional delay. This is why some of us have always preferred the name "instantaneous reclosing." Regardless of what name is used the principle will still be readily accepted by operating men.

In conclusion, it would seem that the authors have perhaps been too modest and too conservative in describing the utility and general application of this new development.

Philip Sporn and **D. C. Prince:** The authors are highly gratified by the reception this paper has received. All the discussion has been of such constructive character as to add materially to the value of the paper.

Mr. LeClair points out that longer reclosing time is available between large systems because of their high inertia, while smaller systems would generally lose synchronism.

Mr. Marquis develops this point further, showing actual case studies and indicating possible advantages of ultrahigh-speed reclosure even with double circuits and even in some cases though synchronism is lost momentarily. Mr. Evans has contributed stability diagrams indicating an advantage in stability from slower fault clearing while Mr. MacNeill indicates the desirability of minimum time in circuit interruption. This difference of opinion is only superficial, since the minimum time between circuit interruption and reclosure is fixed by nature rather than the over-all time of Mr. Evans's hypothesis.

Both Messrs. MacNeill and Schwager comment on the breaker contact travel and the size and complexity of the reclosing mechanism. The contact travel required is a function of the arc-extinction device. In this case 8 inches proved quite adequate for 138 kv. Had the breaker failed to clear in 8 inches the second mechanism would have opened it full stroke. Since mechanical stresses go up as the square of velocity, the minimum stroke was preferred for mechanical reasons.

The complexity of the mechanism was due to its many features of adjustability. Now that the ultimate requirements are known, much smaller departures from standard mechanisms are required.

Mr. Gross points out the possibilities of simplification of line construction by the use of ultrahigh-speed reclosure. The extent to which such simplifications will prove practical must be determined by field experience which everyone will watch with great interest.

Mr. George very modestly refrained from mentioning the important part which he and Mr. Logan have played in the development of "instantaneous" reclosure. They have shown what it is possible to do with standard mechanisms. It was the purpose of the authors in undertaking the development covered by the present paper to study and find out how much more is possible if mechanism and circuit limitations are removed, leaving only physical phenomena limitations to indicate what may or may not be done. The results, I believe, have indicated that speeds of reclosing much faster than any heretofore contemplated are possible. From this point the economics of reclosing must be developed by further system study and particularly by field experience, the final proving ground of all developments.

The Control Gap for Lightning Protection

Discussion and authors' closure of a paper by Ralph Higgins and H. L. Rorden published in the September 1936 issue, pages 1029–34, and presented for oral discussion at the protective devices session of the winter convention, New York, N. Y., January 27, 1937.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): As pointed out by the authors, the sphere gap (if used within proper limitations of spacing) gives a substantially uniform field and therefore has a relatively flat volt-time spark-over curve, while the rod gap, because of its nonuniform field has a volt-time curve which rises rapidly as the time to spark-over is decreased. As a protective device the sphere gap has excellent impulse characteristics and might have been widely used if it did not have 3 inherent disadvantages which are rather serious:

1. The wet 60-cycle spark-over is from $^1/_2$ to $^1/_3$ of the dry value which means that if a level of 3.5 (Lewis and Foust have shown that 13 per cent of switching surges exceed 3.5 times normal voltages: see "Lightning Investigation on Transmission Lines—II," W. W. Lewis and C. M. Foust. AIEE Transactions, volume 50, December 1931, page 1139) times normal is established as the lowest permissible spark-over value for switching surges the sphere gap could not be expected to hold the impulse voltages to less than from 7 to 10.5 times normal, which would not be suitable since the present impulse test gap for transformers rated above 25 kv is between 6 and 7 times normal.

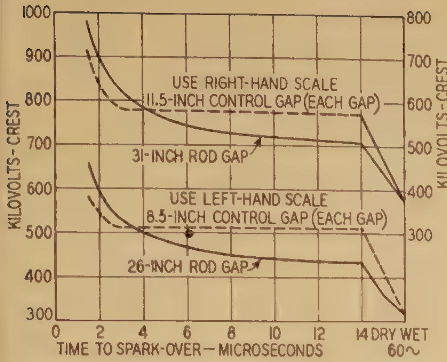


Figure 1. Volt-time curves for OB control gaps (data from figure 5), also rod gaps spaced 26 and 31 inches (positive values plotted)

2. The sphere gap on account of its uniform field is sensitive to any nearby conducting objects, and this limitation combined with the size of the sphere, especially for high-voltage systems, introduces a serious problem in the space required for the gap.

3. The sphere gap is not self quenching, i.e., will not stop power follow, resulting in the possibility of damage to the spheres and the probability of an outage.

The rod gap, on the other hand has much poorer impulse characteristics, but is much less affected by rain. The wet power-frequency spark potential of rod gaps is in general only 10 to 15 per cent lower than the dry value. Thus, for a spark-over time of 2 microseconds the rod gap will have a wet 60-cycle-to-impulse ratio of a little less than 2. For a 31-inch gap the ratio is 1.86, which means that if the rod gap is set so as to have a wet spark-over of 3.5 times normal line-to-ground potential, the voltage at 2 microseconds spark-over time would be 6.6 times normal which is still much too high for safe operation—leaving no margin or factor of safety between the demonstrated strength of the transformer and the potential allowed by the gap. For still higher rates of rise the situation would be still worse, since the potential allowed by the gap would be correspondingly increased.

Following the work of Austin, the authors have attempted to incorporate in the control gaps the impulse characteristics of the sphere gap and the lack of sensitiveness of the rod gap to rain conditions. It seems quite obvious that any scheme which secures the impulse advantages of the sphere gap through control of flux, which is the means the sphere gap itself uses, will be subject to the same wet and dry spark-over values if the same impulse characteristics are secured.

Comparing the wet 60-cycle and 2-microsecond flashover values of the 8.5-inch, and 11.5-inch control gaps as given in figure 5 of the paper a ratio of 1.73 and 1.70 is obtained which is only slightly less than a rod gap having the same 60-cycle spark-over value. These control gap settings apparently correspond to gaps rated 110 kv and 132 kv. I have reproduced the corresponding volt-time curves as figure 1 of this discussion. For times greater than about 4 microseconds the rod gap offers better protection. For times between 1 $^{1}/_{2}$ microseconds and 4 microseconds the data shows the control gap a maximum of 9 per cent below the rod gap. For times shorter than one microsecond more data are needed, since the shape of the curves as drawn do not indicate whether the curves might cross again or not.

Lightning arresters whose spark potentials are not affected by the weather, can be designed for much closer protection than gaps because their spark potential need not be above switching transient levels. They can in general be expected to hold potentials to values ranging from 2.5 to 5 times normal depending upon rating and whether for grounded or ungrounded neutral operation.

When reading the paper I was somewhat puzzled by the statement appearing in the second paragraph in the right hand column of page 1030 relative to the term "flat volt-time characteristic being a misnomer." It seems to me the authors' statement would be true if volt-time curves were only taken through the use of overvoltage. However, volt-time curves may be taken on sphere gaps on the front of the wave in which case flat volt-time characteristic does have a definite meaning.

On page 1031 when concluding the discussion of the "principle of control gaps" the authors state that capacities large enough to control voltage distribution in all kinds of weather must be used. This is usually a rather difficult matter when all kinds of weather are included, and I am curious to know how the authors have accomplished their objective. I know of cases where melting ice has caused unbalance under conditions which appear to be somewhat similar to that used by the authors.

A question arises concerning figure 9 *A*, *B*, and *C* where full-wave spark-over times are given ranging from 20 to 28 microseconds. This time is about twice as long as we have experienced under average laboratory conditions, and the authors' comment on this point would be helpful to those working in this field, I am sure.

On page 1034, at the end of the second paragraph under figure 10, the statement that where "insulation levels are higher than that shown, and where lightning arresters are used in combination with the control gap, higher gap spacings may be used," seems to require some further clarification.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): I wish to discuss this paper partly from the standpoint of protecting transformers in service against lightning with a gap having a flat volt-time curve characteristic, and partly from the standpoint of testing transformers with both long and short waves whose voltage values are controlled by flashing over a gap having a volt-time characteristic similar to that for transformer windings.

We used to consider that a sphere gap had no time lag but we now know that for short time to flashover in the order of one microsecond or less, sphere gaps have time lag.

It is, of course, possible to construct a gap that has no time lag, i.e., the volt-time curve is flat all the way from 60 cycles back to approximately zero time. Such a gap for 132-kv line has been constructed of small metal disks mounted on a rod making use of known resistances and capacitances between disks to control the flux. As pointed out by Mr. McEachron in his discussion, it was found that unless the gap was kept dry, the low 60-cycle wet flashover

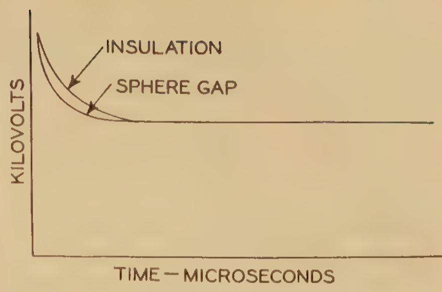


Figure 2. Volt-time curves of sphere gaps and transformer insulation

value required too great a spacing to properly protect against impulse voltages, although it gave considerably better protection for steep wave fronts than the control gap gives. This illustrates the point that when flux control is made use of, the low 60-cycle wet flashover makes it necessary to raise its impulse protective level up close to that of a plain rod gap. The difficulty in this particular case was overcome by enclosing the gap in the top porcelain of a 115-kv bushing to make it weatherproof; but, unfortunately, the gap was not self quenching which means that it probably would not protect the transformer if there were several strokes in rapid succession, since the gap would, no doubt, be destroyed on the first stroke if power current followed through.

If front-of-wave testing of transformers is ever standardized, it might be possible to construct a gap that has the same shape of volt-time curve as transformer insulation. Either such a gap must be developed or a general agreement must be reached on the correct kilovolt values to be applied for short times to flashover of whatever kind of gap is used to chop the wave off.

In fact a gap that is almost (but not quite) good enough for the purpose is already available. I mean the sphere gap.

Tests made on various thicknesses of barriers and with 25-, 50-, and 100-centimeter sphere gaps connected in parallel to control the kilovolts of long and steep-front waves show in all 3 cases that starting with the sphere gap to give the same kilovolts as the breakdown of the barrier on a full wave, then as the voltage is increased the sphere-gap spacing has to be slightly lengthened to keep it balanced with the breakdown of the insulation barrier. The lengthening of the gap continues and then as the time to flashover gets quite short the gap must be shortened. For very short times to flashover the gap length has to be decreased to, or even slightly less than, the spacing that corresponded to the full wave strength of the insulation.

Plotted on a volt-time curve basis the shapes of the 2 curves are as shown in figure 2. These curves mean, of course, that if a sphere gap were used with a constant spacing equal to the full-wave test kilovolts to control the voltage of both long- and short-impulse waves for testing transformers, the factor of safety (i.e., the difference between the breakdown strength and the tested value) would slightly increase as the time to flashover decreased, until the time got quite short and then it would again become the same as for the full wave test. In other words, there would be a band in which the spheres would provide an extra

safety factor during the test. It appears, therefore, that for front-of-wave testing at the present time sphere gaps could be used as a suitable test gap for transformers.

J. R. North (The Commonwealth & Southern Corporation, Jackson, Mich.): The control gap described in the paper by Messrs. Higgins and Rorden offers possibilities as a back-up protective device for use in the higher voltage classifications. However, some of its characteristics approximate a sphere gap and it does not have the ability to clear itself once arc-over occurs. These must be given consideration in its application.

The principal factors in the selection and application of a protective device such as a gap are:

1. The *maximum dynamic voltage* which may occur during fault conditions between the sound phases and ground.

2. The *ability of the protective device* to maintain an adequate protected level on a volt-time basis for both short time and long time intervals.

Considering the dynamic voltage limitations (item 1), studies of actual overvoltages occurring on transmission systems by the joint subcommittee on development and research—EEI and Bell system, as published in Engineering Report No. 30, have shown that the overvoltages arising from system operation are normally of the order of 2 to 5 times the normal voltage to neutral E_n. Therefore, it is generally conceded that a protective device should have a 60-cycle flashover or breakdown voltage under any weather conditions of at least $3^1/_2$ times normal and preferably higher.

An analysis of the performance of the control gap, based upon the characteristics as given in the paper, indicates that with gap settings as would probably be used, the 60-cycle *dry* flashover voltages are above the normal maximum dynamic voltages which may be expected. However, the 60-cycle wet flashover voltages are rather low.

For example, consider the control gap on the basis of giving protection comparable to that of a modern full-voltage arrester and assume 2 systems, one using 46-kv equipment and the other using 161-kv equipment. Figures 3 and 4, of this discussion show the volt-time characteristics of the lightning arrester and the control gap for these conditions. The table I summarizes some of the values shown on these sketches.

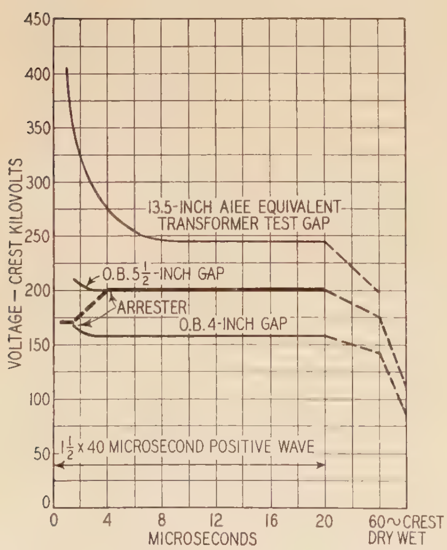


Figure 3. Comparison of OB control gap and lightning arrester, 46-kv class

Table 1

	Short Time					Long Time				
Apparent Voltage (Kv)	Lightning Arrester Break-down (Crest Kv)	Control Gap Setting (Inches)	Control Gap Dry FO	Control Gap Wet FO	Control Gap Wet FO	Lightning Arrester IZ at 5,000 (Crest Kv)	Control Gap Setting (Inches)	Control Gap Dry FO	Control Gap Wet FO	Control Gap Wet FO
46	170	*4	145	85	$2.3E_n$	200	$5^1/_2$	175	110	$2.9E_n$
161	570	*8	440	355	$2.7E_n$	705	12	570	470	$3.6E_n$

* Lowest possible setting with this gap

It will be noted that in the 46-kv classification, the control gap would be given a setting of $5^1/_2$ inches to be equivalent to the voltage across the arrester during discharge and that with this setting the wet flashover voltage of the gap would be approximately 2.9 times the normal voltage to neutral E_n. With the control gap set at 4 inches to give performance equivalent to the breakdown of the arrester gap, the wet flashover voltage would be only 2.3 times E_n. Similar values are obtained for the 161-kv classification. There is a possibility that these low values of wet flashover voltage might result in undesirable outages due to flashover of the gap caused by dynamic overvoltages. It may, therefore, be concluded that the control gap must be set above the protected level afforded by a modern full-voltage-rated arrester in order to eliminate any possibility of flashover due to dynamic overvoltages. The control gap thus acts chiefly as a back-up protective device.

We would like to inquire of the authors as to the effect on the control gap structure of high values of power follow current.

A. C. Monteith (Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.): Considerable work has been done to get the results of the different manufacturers' laboratories into agreement on the minimum impulse test on line insulators and rod gaps. Apparently there is still considerable disagreement for the shorter time lags as rod-gap data for a 138-kv installation at 860-kv give, from the author's data a time lag of 3.3 microseconds and for the Westinghouse data 1.8 microseconds. This difference is significant because it is largely in this zone that the authors can claim superiority of the control gap over the rod gap. It is true that the authors have done considerable work on a direct comparison of rod gaps with the control gap at the minimum impulse flashover and some at $1^1/_2$ microseconds but it is going to be necessary to have the data from the several laboratories on a common basis to be able to co-ordinate the complete substation apparatus.

To those who consider the lightning arrester as the best form of protection (the modern arrester giving protection to from 50,000 to 100,000 amperes without causing an outage) the control gap still offers the same limitations as the rod gap for the protection of transformers.

On solidly grounded systems in the higher-voltage classes the De-ion Protector offers a device that gives protection with the same limitations as the rod gap or control gap but will prevent an outage when it is called upon to operate. Although only test results with positive waves are shown it has very favorable characteristics with negative waves. A band is shown to give some indication of the variation in protection due to variation in particular designs.

These several points are illustrated in the attached figure. The maximum impulse test level on modern transformers is taken from actual tests made by Vogel and Bellaschi.

I. W. Gross (American Gas and Electric Company, New York, N. Y.): These 2 papers center around the problem of protection. The gap paper considers protection to apparatus; the ultrahigh-speed breaker the more comprehensive problem—protection of service. This latter objective requires, first, that interruption of power flow in a circuit should not exceed $^1/_4$ to $^1/_2$ second, as pointed out by Messrs. Sporn and Prince, and second, that the supply equipment such as generators, transformers, etc., be protected against failure. A most economical solution to this entire problem in many cases may be a protective gap of some form in combination with the ultrahigh-speed breaker described by Messrs. Sporn and Prince.

The protective gap, that is, the so-called standard rod gap, has in the past had 2 weaknesses. First, at spacings generally proposed on the basis of impulse tests recommended for transformers, it was recognized the gap would not limit the volt-

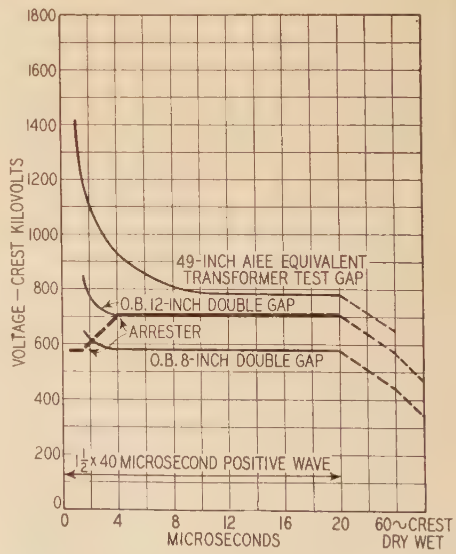


Figure 4. Comparison of OB control gap and lightning arrester, 161-kv class

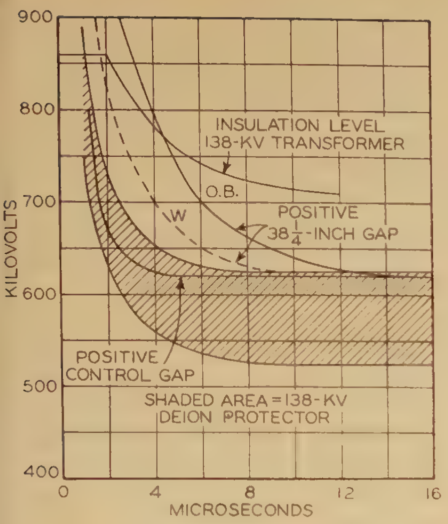


Figure 5

age to a value below the safe impulse strength of standard insulation, on steep wave fronts. On the other hand, if the spacing of the protective gap was reduced to supply protection for steep front waves, an increase in line outages might occur as a result of normal switching surges. In any event, if the protective gap flashed over, whatever its setting, a circuit outage was sure to follow. With the ultrahigh-speed reclosing breaker, however, it should be possible to greatly reduce, if not entirely eliminate line outages due to gap operation.

The control gap described by Messrs. Higgins and Rorden, appears from the data to have considerably better protective characteristics against steep wave front surges than the standard rod gaps, although it still has the undesirable rising characteristics at short time lags.

Based on the data given in the paper a trial design for 132-kv application with standard 132-kv transformer insulation showed that the control gap allows some 20 per cent higher magnitude of switching surge voltage without flashover as compared with a standard rod gap set for the same protective voltage level at $^1/_2$ microsecond. This is a margin that may well be considered when attempting to supply better protection against steep wave fronts, and at the same time reduce line outages due to switching surges to a minimum.

With this set-up of an inexpensive protective gap and ultrahigh-speed reclosing breaker, a reasonable frequency of line flashovers due to switching surges could be tolerated in many cases, as the circuit would be re-energized immediately without objectionable energy interruption. The frequency of breaker operation allowable would depend largely on breaker maintenance, and the degree of risk taken as regards the gap protecting the apparatus on steep wave fronts.

Should such a protective scheme as outlined above prove effective, it would entirely change the present requirements for lightning protection of transmission lines, the continuous ground wire, low tower-footing resistances, and counterpoises not being necessary. While the degree of lightning protection to apparatus with any present known gap appears to be inferior to the protection afforded by modern lightning arresters properly installed, it is well known that our knowledge of the performance of both gaps and lightning arresters under conditions of steep rates of rise of impulses is all too meager. Then too, we have little actual data on the frequency and severity of these steep-front lightning impulses in actual practice. If it is found, by continued field research, that the maximum severity of lightning is less than we are now generally considering, even the present available gaps may prove effective protection to the apparatus, and the high-speed breaker will preserve the continuity of service.

There is one question I wish to ask Messrs. Higgins and Rorden, and that is what is the relative 60-cycle wet and dry flashover of the control gap with and without the porcelain control insulators? The point I have in mind is, if the gap functions, and the power arc disrupts one or more of the control insulators the projecting supports formerly supporting the insulators may be so closely spaced that the gap may have difficulty withstanding normal line voltage, to say nothing of switching surges in the order of 3 to 5 times normal.

Ralph Higgins and **H. L. Rorden**: The control gap is intended to provide protection for the severe lightning surges—those that do the real damage. Existing forms of protection are capable of relieving the less severe transients, such as induced strokes and traveling waves. But failures still seem to occur, and this is evidence that existing protection does not relieve the most severe surges. It is questionable whether failures would occur from the majority of surges which cause present protective devices to function. Indications are that most failures occur at some one severe surge. The control gap is not expected to function for the majority of low-voltage and low-energy surges, since operation of the gap is accompanied by an outage. Its purpose is to maintain a voltage limit at a reasonable margin below the level of station equipment, so that it will operate only when potentials approach dangerous proportions. When direct strokes occur, an outage is almost inevitable, but whether such outage occurs over a directed protective path or breaks through expensive equipment, is a vital question.

The AIEE Standards of Lightning Arresters No. 28 (March 1936) state "Present types of lightning arresters are not in general designed to protect against direct strokes to electric circuits. . . . . ." The control gap is intended for direct-stroke protection. On this basis, their fields of application do not conflict. We do not contend that control-gap characteristics equal that of arresters for low-energy surges. The control gap has a volt-time characteristic independent of energy (current). Arrester characteristics involve volts, current, and time, since the arrester contains resistance material.

Mr. North illustrates an outstanding point in the comparison of the control gap and lightning arresters. In his table of short-time breakdowns, he lists the kilovolts at which the series gap breaks down for 2 rated circuit voltages. In the table of long times, secondary rise or the recovery voltages across the arrester resistance material is given for the same kilovolt ratings. These crest voltages are the potentials to to which the equipment is subjected if the surge is limited to 5,000 amperes. The voltages are about $3^1/_2$ times line-to-neutral (crest). This is of interest because it is mainly above this range ($3^1/_2$ times line-to-neutral) that the control gap is intended to function. It might be said therefore, that arresters can maintain a safe potential for currents below 5,000 amperes, but that the secondary potential rise above that current limit is indefinite. Recent publications have shown that a fair percentage of the more severe surges approach 40,000 amperes.

It would be interesting to know the voltage rise under the 50,000 to 100,000 amperes mentioned by Mr. Monteith, for a high-voltage system. Since arresters in general apparently are not intended for protection against direct strokes (AIEE Standards No. 28) it would be interesting to know if the arresters Mr. Monteith suggests are for other than the lower voltage or distribution systems.

We do not agree with Mr. Monteith's rod-gap figure of 860 kv at 1.8 microseconds for $38^1/_4$-inch spacing, nor can we find any Westinghouse data to substantiate his value. In the figure of Mr. McEachron's discussion, a 31-inch rod gap reaches 860 kv at 2.4 microseconds and is in close agreement with our data. Although our rod-gap curve referred to is from a specific test and is not intended to represent an average, it is in fair agreement with Westinghouse published data also. In ELECTRICAL ENGINEERING, December 1934, Bellaschi and Teague have given very complete curves on rod-gap flashovers, in their paper "Impulse and 60-Cycle Strength of Air." These authors mention that they have measured time on their oscillograms from the point on the wave front corresponding to the 60-cycle flashover voltage. To bring their curves to the basis of measuring time from the origin of the wave, as we have done, would require adding about one microsecond or more to their figures. We are inclined to the opinion that Mr. Monteith has overlooked this correction in offering his suggestion of laboratory disagreement. We appreciate his statement that it is going to be necessary to have the data from the

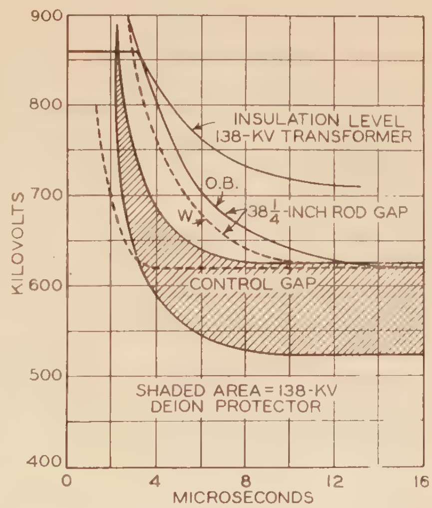


Figure 6. Curves of Mr. Monteith's illustration shifted to time scale measured from origin of wave

several laboratories on a common basis for co-ordination purposes. In the past, it has been the practice of most laboratories to measure voltage from the origin of the wave. We also appreciate his statement that it is largely in this (overvoltage) zone that we can claim superiority of the control gap over the rod gap. On the basis of the suggested correction to his figures, Mr. Monteith should undoubtedly understand the superiority of the control gap. In figure 6 we have replotted his curves corrected approximately to our time scale. The margin between the control gap and the several other curves for the short-time lags is apparent. We observe that the control-gap curve closely parallels the insulation throughout its range, excepting at the short time where an unusual and abrupt change in the insulation curve occurs. An explanation of this "flat" interval, indicating no increase in voltage on front of wave tests would be interesting. Mr. Montsinger (*Electrical World*, February 13, 1937, page 537) apparently does not agree that this interval should be flat.

We are interested in Mr. Monteith's comparison of De-ion tubes with gaps for station protection. Published data suggest these tubes for transmission line service and do not indicate that they are proposed for station protection. It is regrettable that the complete characteristics of the De-ion tube have not been included, since the shaded area tells only part of the story. This area indicates that in the short time intervals, the De-ion tube is equivalent to the control gap, although the complete characteristic is plotted as a band. The upper limit of the tube flashover is shown approximately equivalent to that of the various gaps at minimum flashover, while in the overvoltage range, the control gap curve is approximately an average of the band. At minimum flashover, a spread of 100 kv is apparent. What would this mean under power-frequency wet conditions?

Mr. Gross has discussed a combination which seems to be ideal, particularly for the severe surges. As previously mentioned, an outage is almost inevitable with direct strokes. The high voltage and energy must form a path to ground in any event, and the combination of the control gap with high-speed breakers affords the advantage of protection irrespective of energy and restores the system to service without the usual interruption. Under these conditions, the danger of destroying control insulators is greatly reduced. The switching time, perhaps more than the magnitude of the follow current, would seem to be the major item relative to the ability of the gap to withstand follow current. If a control insulator should be damaged, the result would be loss of advantage of the surge characteristic. The power frequency flashover would be reduced less than 20 per cent. This should not interfere with normal operation until repairs could be effected at later convenience.

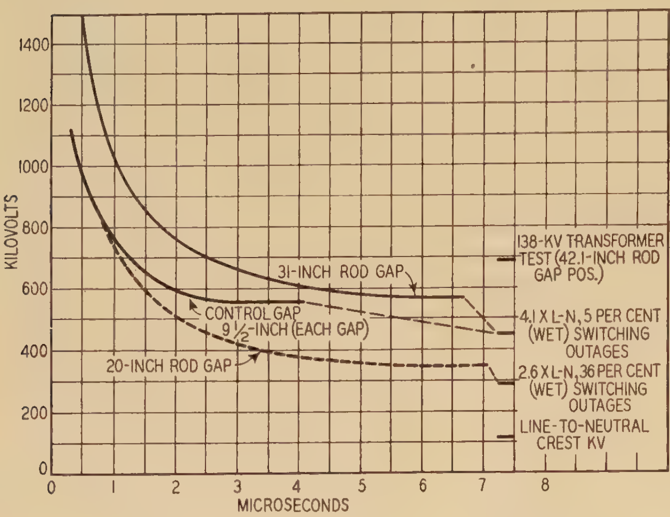


Figure 7. Control gap versus rod gap for 138-kv transformer protection

Negative impulse and switching surges both under rain spray

In commenting on Mr. McEachron's discussion, we wish to emphasize some characteristics of controlling flux in a dielectric field in air. For the same minimum impulse flashover the spacing of a rod gap is $3^1/_2$ or more times that of a sphere gap (spaced within its operating range). A sphere gap has a "flat" volt-time characteristic, while the rod gap has a sloping characteristic (figure 9 *A* and *E* of the control-gap paper). If smaller spheres are used for the same voltage, the spacing is greater and the curve is more sloping. At high overvoltages the rod-gap spacing must be reduced to nearly that of the sphere gap for a balance. The sphere gap and the rod gap are opposite extremes, and partial control of the field results in a spacing and volt-time characteristic proportionately between the two. Thus the general form of a volt-time characteristic may be predicted by the spacing of electrodes at the minimum flashover. For dissimilar electrodes, the same general law holds true for a given polarity.

Mr. McEachron states it is obvious that any scheme that secures the impulse advantages of the sphere gap through control of flux will be subject to the same wet and dry spark-over. We concur in this opinion and this point illustrates the advantage of the control gap. From figure 9 *A*, *D*, and *E* of the paper the control-gap curve is adjusted to be between that of the sphere gap and the rod gap. It follows that its electrode spacing and its power-frequency wet performance are also between the 2 extremes. From the previous explanation and from Mr. McEachron's statements, the control gap has a considerable advantage over the rod gap for impulse characteristics, and is considerably better than the sphere gap for wet flashovers. The control gap is designed to have the best impulse characteristic obtainable with tolerable wet flashover voltages. When so adjusted, the volt-time characteristic of the control gap closely parallels that which has been published (Montsinger, *Electrical World*, November 21, 1936; Bellaschi and Teague, Electrical Engineering, January 1937) to represent transformer insulation. It is therefore only necessary to provide a reasonable margin between the breakdown strength of insulation and control gap flashover to have the protection properly co-ordinated.

Mr. McEachron's figure 1 illustrates the positive impulse comparison between a rod gap and a control gap when adjusted to the same 60-cycle wet flashover. It has been commonly accepted that 60-cycle wet flashovers are equivalent to switching surges. This must be inferred since 60-cycle wet tests are frequently cited and obviously operating voltages, particularly on grounded-neutral systems, do not rise to several times their normal value. Since publication of the paper, we have endeavored to learn if this assumption is justified. On tests with the control gap, we find that it is not. The wave used in our switching-surge tests was obtained by saturating a high-voltage testing transformer with a d-c current and then breaking the circuit abruptly by switching under oil. The wave obtained prior to flashover was very similar to that reported by Bellaschi and Teague in the January 1937 Electrical Engineering ("Dielectric Strength of Transformer Insulation") though somewhat more irregular. Using these switching surges as the criterion of operating tolerance, we have attempted to show the complete performance which Mr. McEachron's figure 1 is intended to illustrate, in figure 7. The tests were made with negative polarity since direct strokes are predominantly negative (Lewis and Foust show 95 per cent, *G. E. Review*, November 1936). We have selected a 31-inch rod gap so these results will compare with Mr. McEachron's illustration for a 132-kv system. These test results are obtained by direct comparison of the 2 gaps and with oscillographic records. The analysis is based on the assumption that the limits of a gap as a protective device are its ability to relieve high overvoltages, and its performance for switching surges in rain. With switching surges applied, the 31-inch rod gap was found to balance with a control gap spaced with each gap $9^1/_2$ inches. The flashover measured 445 kv, which according to Lewis and Foust, should result in 5 per cent switching outages. When dry, the control-gap outages will be less but the rod gap will not change greatly. With high overvoltage negative surges applied to the same gaps, it was found that the rod gap had to be reduced to 20 inches to balance with the control gap having the same spacing as in the switching-surge tests. If a rod gap of 20-inch spacing were installed on a 132-kv system, its switching surge flashover would be 2.6 times line-to-neutral and would cause 36 per cent switching outages—over 7 times that of the control gap having the same short time impulse protection.

We are not quite sure what Mr. McEachron means by a rod gap offering greater

protection for times greater than 4 microseconds. By his comparison, the rod gap will flash over at a lower voltage for times greater than 4 microseconds. This, of course, means more unnecessary outages and it is not quite clear why the protection should be any better as long as the gap will flash over in any event before the voltage rises to a dangerous level. We consider an ideal protective curve one that parallels that which it is to protect. Relative to the statement that more data are needed at times less than one microsecond, we wish to point out that the curves published are intended for operating data, so that the gap may be adjusted to define a minimum flashover level. The high overvoltages are not plotted in these curves because we do not rely on indirect comparison where small deviations due to personal analysis result in uncertainty regarding the actual performance. We have cases on record, and have observed in other data, where identically the same time for flashover of a gap was recorded by a cathode ray oscillograph at voltages differing by 100 per cent in the short-time range. A graph of such data is a matter of personal judgment and it is difficult to plot a line to represent such phenomena as accurate performance. Too frequently conclusions are drawn by making indirect comparisons and stressing exactness where precision is not justified. We believe the ultimate criterion of protection is to be found by a comparison where it is possible to determine relative performance directly. Therefore, we do not attempt to show that we differ by some questionable margin from other data through the medium of comparing curves which should preferably be shown as a band.

That the parallel test method adequately illustrates the advantage of the control gap is illustrated in figure 8. This figure, with the control-gap equivalent added, is reproduced from the August 1934, *G. E. Review,* "Lightning Protection of Power Transformers Connected to Overhead Circuits," by K. B. McEachron. This curve, particularly at minimum flashover and at the high overvoltages, is substantiated by Mr. F. J. Vogel ("Adequate Impulse Tests," *Electric Journal,* January 1935). From this curve, according to Mr. McEachron, a transformer is adequately protected at the high overvoltages by a rod gap spaced 55 per cent of the spacing which would protect the transformer at minimum flashover (100 per cent). The dashed curve superimposed on this figure illustrates that the control gap is approximately 10 per cent better throughout its entire range than Messrs. McEachron and Vogel show is necessary to protect power transformers. Although Mr. McEachron's curve applies only to positive polarity, Mr. Vogel illustrates that on negative polarity the same general percentages obtain, particularly at the minimum flashover and at the high overvoltages.

The question relative to spheres having a "flat" volt-time characteristic is answered by inspection of our figure 9 *E*. This applies to any type of test and particularly to front of wave testing. Such characteristics are shown to have a rising voltage curve in the short time range. Frequently, the curve is plotted as a straight horizontal line from minimum flashover at about 2 microseconds to infinity. It is not possible to obtain long time lags in sphere gap flashovers. Some curves lead us to believe that at the minimum flashover, any time is obtainable. Actually there is no test point obtainable in the "flat" region. The curve ceases to exist once it becomes flat. Long time lags are associated with corona formation and for sphere-gap curves to be plotted illustrating that long times to flashover are obtainable under any condition (with spacing within their normal operating range) is a misnomer.

We concur that it is not easy to maintain electrical stability in multigaps under all weather conditions. In the control gap, this has been accomplished by using insulators having a capacitance approaching the range of coupling condensers, which are known to give satisfactory performance. By his question of unbalance due to melting ice, Mr. McEachron is undoubtedly concerned only with operating characteristics since we are not normally concerned with lightning storms in freezing weather.

We appreciate Mr. McEachron suggesting an explanation of variations in time to flashover at minimum voltage. This further justifies our contention that such characteristics should be plotted as a band rather than a line. The oscillograms illustrated were chosen at random during the tests and are not at all unusual. Inspection of our figure 9 *A* and *B* illustrates that while the oscillograms show times of the order mentioned, the adjacent volt-time curves show that minimum flashover is reached in about 16 microseconds. At minimum, the range in time to flashover for gaps which are dependent upon corona formation is more than 100 per cent. Successive flashovers showing 10 to 25 microseconds for gaps of the order shown are common, without a measurable difference in voltage. This band becomes narrow rapidly with increasing overvoltages, but is still measurable on front-of-wave tests. The inadequacy of drawing conclusions by representing such a characteristic as a line is apparent.

The previous discussion has undoubtedly answered Mr. McEachron's question regarding the use of the control gap as back-up protection, since the control gap characteristic closely parallels that of insulation. A higher insulation level could be accompanied by a corresponding control-gap spacing. Where the control gap is used in conjunction with arresters, it is expected that the arrester will perform first and relieve part of the surge. The control gap should flash over only when potentials beyond the scope of the arresters are reached and therefore a somewhat closer margin might be adopted.

Mr. Montsinger points out that sphere gaps have a time lag when flashover is of the order of one microsecond or less. Mr. Montsinger has shown (*Electrical World,* November 21, 1936) that his approximate equivalent of transformer insulation has a time lag when flashover is of the order of 3 microseconds or less. He therefore shows that a sphere-gap characteristic is considerably faster than that of major insulation. The control gap has a characteristic very similar to that which Mr. Montsinger has shown to represent such insulation. His illustration of a sphere-gap curve merging with insulation at high overvoltages is of interest, since this characteristic is contrary to the general trend of flashovers. We are also interested in Mr. Montsinger's statement concerning a no-time-lag gap.

Such a characteristic is undoubtedly possible in a multigap so unbalanced that successive rather than simultaneous flashovers determine the minimum breakdown. We think his suggestion that a sphere gap be used for transformer testing is excellent, although its characteristic, as he shows, is faster than transformer insulation. The sphere gap lends itself readily to laboratory tests, is easily adjustible, and complete calibrations are available, but it is not suitable for protection in service. The control gap on the other hand is not as desirable for laboratory testing but lends itself readily to station protection.

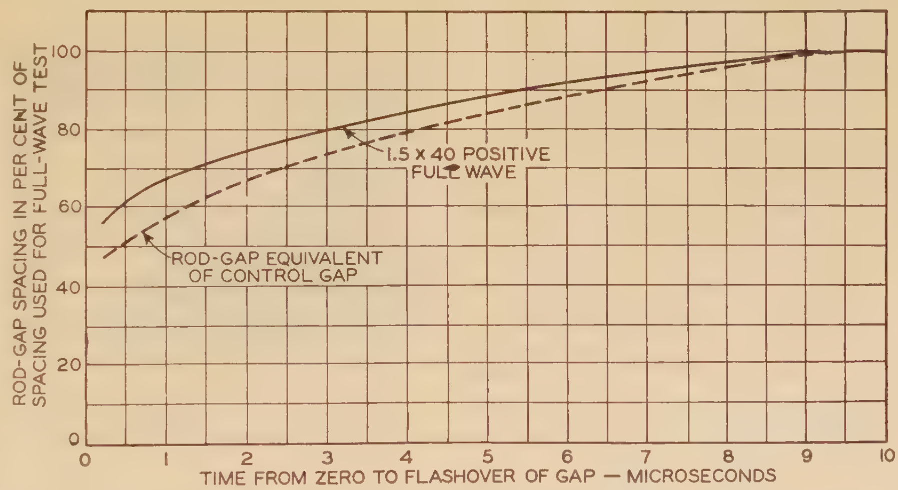


Figure 8. Rod-gap spacings to give a constant factor of safety in power transformers (based on approximate major insulation strength) from "Lightning Protection of Power Transformers Connected to Overhead Circuits," by K. B. McEachron, "General Electric Review," August 1934

News

Of Institute and Related Activities

Milwaukee, Wis., Is Host to 53d Annual Summer Convention

In 1906 the Institute held its 23d annual summer convention in Milwaukee, Wis. Just 31 years and 3 weeks later, Milwaukee again played host to the Institute, this time for its 53d annual summer convention (none was held in 1917). Several unusual features marked the program of the 1937 convention held June 21–25, with headquarters at the Schroeder Hotel.

All these features are covered in this issue of Electrical Engineering, which brings to all members of the Institute not only a comprehensive news digest covering the high lights of the convention activities outlined in programs previously published, but also the full text of the 2 principal special addresses delivered by men prominent in the engineering profession, and several other special presentations of interest and value to the membership at large.

Annual Business Meeting

With some 250 or more persons in attendance, and with K. L. Hansen, general chairman of the 1937 summer convention committee, presiding, the opening session convened Monday morning, June 21, in the Crystal Ball Room of the Schroeder Hotel. Chairman Hansen outlined briefly the several unusual features on the program and then introduced as honorary chairman and "an outstanding Milwaukee personality . . . for many years associated with electrical developments on a large scale," General Otto H. Falk. General Falk in his brief but generous message of warm welcome mentioned the fact that the last AIEE summer convention held in Milwaukee was in 1906.

On behalf of the summer convention committee Chairman Hansen paid special tribute to General Falk and to "Milwaukee industries that have contributed so generously to make this convention a success . . . contributed by permitting their men to use their time for convention purposes, financial contributions, hospitality, inspection trips, and in other ways." At this point the gavel was turned over to President MacCutcheon who presided for the annual business meeting.

Reports of the Board of Directors and the Committee of Tellers

On behalf of the Institute, President MacCutcheon responded to General Falk's message of welcome. The president's address, "The Engineer of Tomorrow," is reproduced in this issue (pages 941–3).

The customary digest of the annual report of the board of directors for the fiscal year ending April 30, 1937, was presented by National Secretary H. H. Henline. Mr. Henline pointed out that the report, published in full in the July issue of Electrical Engineering, is made up of a large number of brief reports covering all major phases of Institute activities, and many activities in which the Institute co-operates jointly with other organizations. In this report is a wealth of information of interest and value to every Institute member. One of the features of the year's activity has been the prodigious amount of time, effort, and energy spent by President A. M. MacCutcheon in visiting some 46 Institute Sections and 20 educational institutions and

President A. M. MacCutcheon (left) exchanging greetings with General Otto H. Falk, honorary chairman of the general summer convention committee

Student Branches in 29 states, the District of Columbia, and Canada; in attending the 2 national conventions and 2 District meetings, and several District student conferences held during the year; and in effectively stimulating the activities of many Institute committees.

Concerning general activities Mr. Henline reported that the 2 national conventions and 2 District meetings held during the year were well attended. He stated also that during the year new records had been set in Section activities, with a total of 621 meetings reported including numerous group meetings for special discussions, and in Student Branch activities, with 1,363 Branch meetings reported. With the organization of Student Branches at Columbia University, New York, and at Tulane University, New Orleans, La., there are now 119 Branches functioning.

Further with reference to Section activities, Secretary Henline reported that the organization of the East Tennessee Section brought the total number of Sections now functioning up to 62, with the formation of several others in prospect. During the past year a total of 23 Sections sponsored special activities, 20 holding meetings of special types in addition to their regular meetings, and 3 others conducting educational courses. The survey and reallocation of Section territory was reported as having been completed by the special committee that has been working on it since 1935, and approved by the board of directors to become effective as of August 1, 1937. In general principle, the plan so modifies and enlarges the territory assigned to Sections as to place within Section territory all members residing in continental United States with the exception of approximately 300 residing in scattered and sparsely settled areas neither contiguous nor tributary to Section territory. For convenience and accuracy, county boundaries now are used in specifying Section territory. All District officers and the officers of all Sections involved in territorial changes have been given full information concerning the changes, and membership lists for each Section as of August 1, 1937, will be prepared on the new basis.

In commenting upon the report of the membership committee, National Secretary Henline called attention to the following figures:

Item	May 1, 1936	May 1, 1937
Total membership	14,600	15,308
Applications from Enrolled Students	631	716
Other applications	946	1,040
Enrolled Students	4,049	4,503

Further details concerning Section and Branch activities for the year 1936–37 are given in the comprehensive annual report published in the June 1937 issue of Electrical Engineering, beginning on page 762. Other items have been published during the year.

The report of the committee of tellers was published in the July issue of Electrical Engineering, page 913, along with a report covering the election of honorary members.

Treasurer's Report

An independent and personal verification of Institute accounts as covered in the auditor's statement published as a part of the report of the board of directors, was reported by National Treasurer W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y. He reported that further returns had been made to the reserve capital fund in compensation for withdrawals required for

Institute activities during 1932–33–34, at the same time accommodating increased appropriation to the publication committee and to certain other committees for the further extension and development of Institute services to its members. He urgently recommended continuance of a conservative financial policy in order that future possible economic disturbances of a general nature should not injure nor unduly curtail Institute activities.

Table I. Analysis of Attendance at 1937 Summer Convention, Milwaukee, Wis.

Classification	Dist. 1	Dist. 2	Dist. 3	Dist 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Foreign	Totals
Members	74	83	55	15	359	7	20	13	11	3		640
Enrolled Students					62							62
Men guests	2	7	3	1	131		3	1	2			150
Women guests	19	15	10	4	141	3	11	5	6	1		215
Totals	95	105	68	20	693	10	34	19	19	4		1,067

Prize Awards

Chairman H. S. Osborne of the AIEE committee on award of Institute prizes presented formally the committee's report, and President MacCutcheon made the presentations to the recipients present, Mr. P. S. Millar and Professor H. E. Edgerton. Complete text of the report may be found on page 756 of ELECTRICAL ENGINEERING for June 1937.

Lamme Medal for 1936 Presented to Doctor Frank Conrad

"For his pioneering and basic developments in the fields of electric metering and protective systems" Doctor Frank Conrad (A '02) assistant chief engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., received during the annual summer convention business session at Milwaukee, Wis., the ninth in the series of AIEE Lamme Gold Medals. This was the second major award made by the Institute to Doctor Conrad, the earlier award having been that of the Edison Medal for 1930.

One of 3 bequests provided in the will of Benjamin Garver Lamme (deceased July 8, 1924), the AIEE Lamme Medal was established for the encouragement and recognition of "meritorious achievement in the development of electrical apparatus or machinery." The other bequests were made to The Ohio State University, Columbus, and to the Society for the Promotion of Engineering Education (this year's awards are announced elsewhere in this issue).

Lamme Career Outlined by President-Elect Harrison

As a background for the presentation of the Medal to Doctor Conrad, President-Elect W. H. Harrison presented the following outline of the life of Lamme as indicative of the circumstances that led to the founding of the Medal:

"Fortunately, Mr. Lamme recorded his life history, a fascinating story, from his boyhood on the farm, country schooling, natural bent for mechanical things, devotion to elementary mathematics, engineering course at The Ohio State University, and affiliation with the Westinghouse Electric and Manufacturing Company that began in 1889 in a testing department and ended with his death in 1924 as its chief engineer.

"His achievement as the guiding genius and inspirational force of the engineering work of that great organization, and in particular his contributions to the advancement of the science of electrical-machine design, hardly need to be reviewed at any Institute gathering. Monuments to the brilliance of his mind, to his industry, to his courage, to his imagination, are to be found literally wherever electric energy is generated and applied.

"Beginning early in his career he gave generously of his time and knowledge to affairs of the Institute, participating in its deliberations and particularly in its technical discussions. He served in many capacities, perhaps the most noted being his service on behalf of the Institute on the Naval Consulting Board of the United States from 1915 to 1919. He was honored by the AIEE in 1919 by the award of the Edison Medal, the most distinguished award the Institute can bestow. From his Alma Mater, Ohio State University, he was the first to receive the Joseph Sullivant Medal in recognition of the value of his work to the world. Pioneering in a field when so little was known of the science of electricity, even as to its fundamentals, and full well realizing the necessity for training and education, he gave freely to these activities. It was like the man to establish in his will a medal for the advancement of a profession he cherished and to which he contributed so much. This significant and highly prized medal will continue to serve as an inspiration to the engineers of the future."

Medalist Introduced by A. M. Dudley

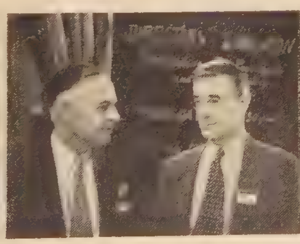
With enthusiasm for the human qualities of the medalist as well as for his versatile technical genius, A. M. Dudley (A'08, F '13) marine electrical engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., outlined the more outstanding features of Doctor Conrad's career:

"To do justice in a casual quarter of an hour to the lifetime accomplishment of a busy man is unthinkable, and to mention a few of the high spots of what he has done is to create the thought that perhaps one has omitted many of the best . . . .

"In 1890 at the very tender age of 16 years, without benefit of even a complete grade-school education, Frank Conrad went to work in the Garrison Alley Shops of the Westinghouse Electric and Manufacturing Company as a bench hand. His biography gives us an intriguing picture of a clever mischievous boy filled with an insatiable curiosity about scientific measuring instruments and about electricity. As the result of some suggestions that he made about the work which he was doing with his hands, he was selected to go to the testing floor as a laboratory assistant. While there he worked on meters and laid the groundwork of that work for which he is being cited today. He also worked on arc lamps.

"In 1904, when I first knew him, he had been designated general engineer, as a free lance under the direction of the vice-president of engineering to work on any or all engineering problems to which he might be assigned. He followed that period with work on circuit interruption on the New Haven Railroad electrification. A little later he worked on starting, lighting, and

Left to right: Director E. S. Lee of Schenectady, N. Y., National Secretary H. H. Henline of New York, N. Y., Past Vice-President W. S. Rodman of Charlottesville, Va., and J. F. H. Douglas, chairman of the convention technical program committee



Vice - President Mark Eldredge (left) of Memphis, Tenn., conversing with Director-Elect Vannevar Bush of Cambridge, Mass.

W. O. Helwig (right) chairman of the convention registration and housing committee, checking notes with K. L. Hansen, general chairman of the summer convention committee

Left to right: Past Chairman H. H. Race of the Schenectady Section, National Treasurer W. I. Slichter of New York N. Y., Past Chairman F. C. Young of the Rochester Section and Past Vice-President C. R. Higson of Salt Lake City, Utah

Future AIEE Meetings

Pacific Coast Convention
Spokane, Wash., Aug. 30–Sept. 3, 1937

Middle Eastern District Meeting
Akron, Ohio, Oct. 13–15, 1937

Winter Convention
New York, N. Y., January 24–28, 1938

North Eastern District Meeting
Pittsfield, Mass., Spring 1938

Summer Convention
Washington, D. C., June 20–24, 1938

ignition for automobiles. During the War he rendered signal service to our government in the matter of radio communication. At present he is a Lieutenant Commander in the Naval Reserve. . . . He is a sage counselor of youth; young men come to him and enjoy working with him . . . . In 1921, he was appointed assistant chief engineer, a title which still serves to designate the man to whom you can carry any kind of questions you may have.

"He followed that with some work on rectifiers, radio broadcasting, short wave radio, and . . . on voting machines.

"Four times have medals come to him . . . : In 1925 the Morris Leibmann prize of the Institute of Radio Engineers; in 1933 the John Scott Medal of the City of Philadelphia; in 1930 the AIEE Edison Medal; in 1936 the AIEE Lamme Medal . . . In 1928 the University of Pittsburgh conferred upon him the degree of doctor of science. He is a Fellow in the Institute of Radio Engineers, and a Fellow of the AIEE.

"What has he done, briefly, to deserve all this acclaim? First, unquestionably comes radio broadcasting, and perhaps more important, we would have to mention shortwave radio development . . . . Following these there is a long list of distinguished design accomplishments along many lines, including the arc lamps, meters, automotive equipment, and radio that has been mentioned; in all he has something like 250 patents to his credit, and most of these have been manufactured, or are still being manufactured in some form.

"Known to only a few is Doctor Conrad's interest in biology and physiology; in conjunction with one of the doctors in Columbia Hospital in Wilkinsburg, Pa., he developed a method for draining fluid from an infected lung in pneumonia cases, which method has been highly successful and probably will be used much more. It is characteristic that in connection with that work he had developed by one of the big rubber companies a special form of rubber tubing which has a passage through the middle to conduct ingoing liquid and corrugations around the outside to conduct outgoing fluid for use in cases of irrigation or removal of fluid.

"Frank Conrad and his work stand to me for the spirit of service . . . for the aristocracy of intellect as shown in the power of his scientific curiosity and his creative imagination . . . for the flowering of this great democracy in which we live."

Doctor Conrad Responds

In responding to Mr. Dudley's address, Doctor Conrad stated that his pleasure in receiving the Lamme Medal is "enhanced by the fact that the Lamme Medal was provided by the generosity of a man who to an extent was responsible for the part I was enabled to take in the development of electrical measuring instruments." In recounting some of the problems incident to the development of the a-c system, Doctor Conrad said: "It became imperative that means be provided for observing all aspects of this new industrial service, and through fortune it happened that I was privileged to play a part in the subsequent development of a-c instruments . . . . Aside from the Siemens' dynamometer and the Kelvin balance, which were adapted to the laboratory but not to the station switchboard, there were some types of measuring instruments in existence at the time that did give some approximation of correct readings on alternating current although they had been designed for d-c use. Attempts were made to adapt these instruments to a-c operation by calibrating them, especially for the particular a-c circuit in which they were to be used.

"Our crude cut-and-try methods of development soon taught us that it was necessary to subdivide or laminate any iron used in the magnetic field. Also if the coils were wound on metal spools, these spools had to be slotted in some manner to avoid a closed circuit around the magnetic core. In a few years a line of instruments was made available in which the voltmeters and the wattmeters had moving coils and the ammeters had moving iron armatures; these were comparable in accuracy to those of the present, although they were unwieldy and expensive . . . . Some years later the general principle of utilizing the current induced in the moving element, employed by Shallenberger in his pioneer current meter, was incorporated in new designs of compact switchboard instruments. This type of instrument constituted an intermediate step in instrument design and made possible the use of a scale length which extended around almost the entire circle.

"As often is true, fashions in instrument design now have swung back to those early days, and at present the induction type of instrument, excepting the watt-hour meter, has been almost supplanted by types corresponding to the first moving-iron-core and moving-coil instruments. Great advances made in the improvement of magnetic materials and complete understanding of the principles involved, now permit the production of instruments of many sizes and types, completely satisfactory as to accuracy and dependability."

Table II. Summer Convention Attendance During Recent Years

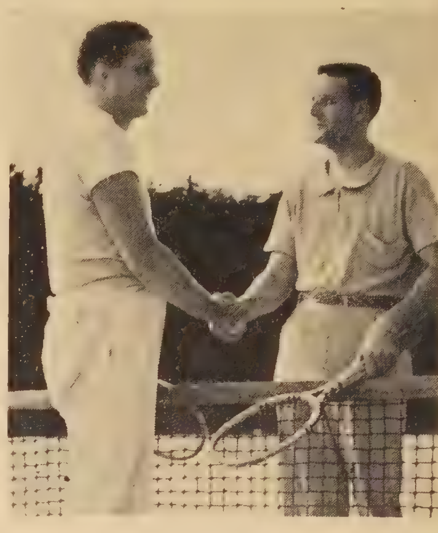
1937	Milwaukee, Wis.	*(5)	1,067
1936	Pasadena, Calif.	(8)	715
1935	Ithaca, N. Y.	(1)	904
1934	Hot Springs, Va.	(4)	351
1933	Chicago, Ill.	(5)	968
1932	Cleveland, Ohio	(2)	1,022
1931	Asheville, N. C.	(4)	525
1930	Toronto, Ont., Canada	(10)	1,110
1929	Swampscott, Mass.	(1)	1,000
1928	Denver, Colo.	(6)	500
1927	Detroit, Mich.	(5)	1,200
1926	White Sulphur Spgs., W. Va.	(2)	350
1925	Saratoga Spgs., N. Y.	(1)	900
1924	Chicago, Ill.	(5)	750
1923	Swampscott, Mass.	(1)	1,616
1922	Niagara Falls, N. Y.	(1)	950
1921	Salt Lake City, Utah	(9)	426
1920	White Sulphur Spgs., W. Va.	(2)	314

* District numbers in parentheses.

Other Convention Features

Technical Sessions

Two special sessions featured this year's formal program. One was an all-morning session devoted partly to a special address "The Engineer in a Changing World" by Ralph E. Flanders, past president of the American Society of Mechanical Engineers, and partly to a general discussion of the subject "How can the Institute programs be made of greatest value to the membership?" which was introduced by 7 discussions prepared by prominent Institute members. The second special session was an evening general meeting addressed by Director-Elect Vannevar Bush on the subject "The Engineer and His Relation to Government." These 2 special addresses and the 6 discussions mentioned are published in full elsewhere in this issue as part of the convention report.



S. B. Crary, Jr. (left) of Schenectady, N. Y., winner of the Mershon tennis trophy, being congratulated by W. J. Morrill of Fort Wayne, Ind., runner-up

The 10 regular technical sessions accommodated the presentation and discussion of some 39 formal technical papers and 4 technical presentations of a special character. In addition, and for the benefit of the specialists particularly interested, 2 conference meetings were included in the schedule: one on field problems, and one on electrical apparatus for 3-phase arc furnaces. These 2 technical conferences provided the opportunity for informal discussion of several topics of specialized interest.

Attendance

With its total registered attendance of 1,067, Milwaukee sets an attendance record for summer conventions that has not been exceeded since the summer convention held in Detroit in 1927. In one of the accompanying tabulations is given an analysis of the attendance at the current summer convention; in another table are given comparative registrations over a period of years.

Entertainment

A generous and well organized program of entertainment, and special inspection trips involving attractive entertainment features, was provided by the Milwaukee committee for both men and women. The entertainment program opened Monday evening, with some 400 men in attendance at a stag buffet supper and smoker held at the Milwaukee Athletic Club, and with the women entertained at a buffet supper in the banquet room of the Schroeder Hotel. On Wednesday evening, some 470 men, women, and children, enjoyed a 2-hour boat trip on Lake Michigan. In spite of record hot weather, more than 400 were reported present at the president's reception and dinner-dance held Thursday evening at the Schroeder Hotel. The entertainment program was terminated by a "farewell gathering" for dinner Friday evening at the Bluemound Country Club.

Provisions for the reception and entertainment of the women were thoughtfully arranged and effectively carried out. Features arranged especially for the women included special inspection trips Monday and Tuesday, a tea Tuesday afternoon, a luncheon and card party at the Wisconsin Club Wednesday, "Country Club Day" Thursday at the Tripoli Country Club, and Friday open for activities of individual choice.

Golf

Major golf events, of course, were the competitions for the Mershon and the Lee trophies and the District team contest.

The Mershon trophy is open for national competition among Institute members on the basis of match play under handicap. The 16 who qualified during the first day's play (low net score) were A. H. Sweetnam, Boston, Mass.; T. O. Rudd, New York, N. Y.; R. M. Darrin, Buffalo, N. Y.; R. A. Wheeler, Milwaukee, Wis.; H. T. McPhail, Denver, Colo.; G. V. Smith, Mansfield, Ohio; H. P. Kuehni, Schenectady, N. Y.; G. A. Kositzky, Cleveland, Ohio; Lee Cook, Dallas, Texas; W. O. Helwig, Milwaukee, Wis.; R. H. Fair, Omaha, Neb.; J. H. Irwin, Chicago, Ill.; R. G. Lorraine, Schenectady, N. Y.; H. O. Anderson, New Haven, Conn.; C. H. Teskey, Cleveland, Ohio; G. R. Canning, Cleveland, Ohio. Out of this field emerged:

Winner—C. H. Teskey (A'32)
Runner-up—G. A. Kositzky (M'22, F'29)

Mr. Teskey will be the second to have his name engraved on the present trophy, which is the third cup donated by Past President Ralph Mershon, the first having been won in 1931 by L. F. Deming of Philadelphia, Pa., after having withstood competitions since 1912; the second having been won in 1935 during the summer convention at Ithaca, N. Y., by L. R. Keiffer of Cleveland, Ohio, after having been in competition for only 4 years. The regulations governing the present trophy are that it shall remain on permanent exhibit at AIEE headquarters in New York bearing engraved upon it the name of the winner of each successive year's competition.

A group of summer convention golfers (left to right): President A. M. MacCutcheon of Cleveland, Ohio, Chairman Lee Cook of the Dallas Section, Chairman E. D. Freeman of the Oklahoma City Section, and W. O. Helwig, chairman of the convention registration and housing committee

The Lee trophy, presented in 1932 by the late Past-President W. S. Lee is awarded each year to the player having the lowest net score for 36 holes, and must be won twice by the same player for permanent possession. The results of the 36-hole medal play at Milwaukee were:

Winner—G. A. Kositzky (M'22, F'29) of Cleveland, Ohio

Runner-up—G. R. Canning (A'32) of Cleveland, Ohio

Mr. Canning narrowly missed winning permanent possession of the trophy. With the newest addition, the names now appearing on the Lee trophy are:

1932—C. H. Teskey, Cleveland, Ohio
1933—G. R. Canning, Cleveland, Ohio
1934—F. M. Craft, Atlanta, Ga.
1935—A. H. Sweetnam, Boston, Mass.
1936—H. S. Warren, Los Angeles, Calif.
1937—G. A. Kositzky, Cleveland, Ohio

District team competition, on the basis of 36-hole medal play was won by a team representing the Great Lakes District with a total of 667 gross for the 36 holes: G. F. Crowell (A'20, M'36), Milwaukee; J. H. Irwin (A'20), Chicago; E. L. McClure (A'37), Milwaukee; R. A. Wheeler (A'21), Milwaukee.

Each of the several day's play was featured by various special prizes. The winners of these special awards were too numerous to record here.

The golfing events for men were played at the Tripoli Country Club Monday and Tuesday afternoons, June 21 and 22, at the Ozaukee Country Club Wednesday and Thursday afternoons, June 23 and 24, and at the Bluemound Golf and Country Club Friday, June 25. The dinner dance held Friday evening at the Bluemound Country Club was intended to be the grand finale for the convention, at which prizes for golf and tennis competitions would be awarded. Early departures from the convention, however, restricted the attendance at this final affair.

Membership—

Mr. Institute Member:

Please concentrate for just one minute on this thought: What man among your associates would receive most benefit from membership in the Institute?

Think over the list of men who are headed toward higher responsibilities, who would be broadened by the contacts with more experienced men in their profession, and who would profit by the discussions at the Section meetings.

Which one stands out? That man needs the Institute and the Institute needs and will welcome his membership. Why not speak to him right now?

A. B. Cooper

Vice-Chairman, District No. 10
National Membership Committee

Tennis

The annual tennis tournament was held on the clay courts of the Milwaukee University School beginning Monday afternoon, June 21, and comprised both singles and doubles for men. The principal formal competition, of course, was for the Mershon trophy. Out of a field of 8 entrants in the singles tournament, W. J. Morrill (A'25, M'35) of Fort Wayne, Ind., and S. B. Crary, Jr. (A'31) of Schenectady, N. Y., emerged into the semifinals. Mr. Crary won the final match, and the privilege of being the third to have his name engraved on the present Mershon trophy which was donated in 1935 by Past-President Ralph Mershon to replace an earlier trophy that was permanently won in 1934 by E. F. Lopez (A'16, M'18) of Mexico City. The names now appearing on the current Mershon trophy are:

1935—Allen O. White, Washington, D. C.

1936—E. F. Lopez, Mexico City, D. F., Mex.

1937—S. B. Crary, Jr., Schenectady, N. Y.

Stipulations governing the present trophy are that it shall remain on permanent exhibit at Institute headquarters with the names of successive winners engraved upon it.

Annual Conference of Officers, Delegates, and Members Held at Milwaukee, Wis.

SPONSORED jointly by the Sections committee and the committee on Student Branches, the annual conference of officers, delegates, and members of the Institute assembled for 2 busy sessions Monday and Tuesday afternoons, June 21 and 22, 1937, at the Hotel Schroeder in Milwaukee, Wis., as one of the regular activities of the summer convention. In attendance at the sessions were delegates from 57 of the Institute's 62 sections, 6 of the 10 District secretaries, counselor delegates from all 9 of the Districts in which committees on student activities have been organized, and many other local and national officers of the Institute and members actively interested in the conduct of Institute affairs. A complete list of the authorized representatives present is given in the accompanying tabulations. W. H. Timbie, chairman of the Sections committee, presided.

Topics discussed were essentially as outlined in a program mailed to delegates and others in advance of the meeting:

Monday Afternoon, June 21

1. Opening remarks—President A. M. MacCutcheon.

2. Presentation of summary of past actions of delegates' meetings (1931 to date).

3. Presentation of summary of Section "self analysis" questionnaires.

4. Situation regarding registration of engineers.

(*a*) In the East—representative from New York Section.

(*b*) In the Midwest—representative from Chicago Section.

(*c*) In the West—representative from Los Angeles Section.

(*d*) General comments on Sections activities and present attitude of AIEE board of directors regarding registration—President MacCutcheon.

5. General discussion on above subjects.

Tuesday Afternoon, June 22

6. Publication policy.

(*a*) Report from publication committee—I. M. Stein, chairman.

(*b*) Report from technical program committee—R. N. Conwell, chairman, of a special subcommittee of the technical program committee.

(*c*) Mechanics and economics of past, present, and proposed schemes—G. Ross Henninger, editor.

(*d*) General discussion.

7. Miscellaneous subjects.

Section and Branch activities were covered in some detail in a report published in the June 1937 issue of ELECTRICAL ENGINEERING, beginning on page 762. Inasmuch as this information thus already had been circulated to the entire membership, no pamphlet copies of the report were prepared for use at the conference, and nothing remains to be reported here.

President MacCutcheon Opens Session

In brief opening remarks made at the request of Chairman Timbie, President MacCutcheon described the Institute as being "really only an organization of Sections," and sought to emphasize the responsibility of each Section delegate to these summer conferences. In speaking of the necessity for constantly planning for the future, President MacCutcheon spoke strongly of the value to the board of directors of well considered recommendations emanating from these annual conferences. He pointed out that all past recommendations of the conferences had received the attention of the board of directors and that many of them had been adopted as recommended.

In a manner supplementing the remarks of President MacCutcheon, Doctor H. H. Race, Schenectady, N. Y., of the Sections committee made available to members and delegates present a mimeographed record of all actions taken by the annual conferences since 1931, together with brief information as to subsequent action taken and disposition made of each recommendation. This report had been compiled by the Sections committee for the meeting partly as a matter of record and partly to avoid spending unnecessary time during the conference session in the discussion of matters already disposed of.

Section Self-Analysis

Desirous of assisting in local Section activities, the AIEE Sections committee sent a questionnaire to each Section, March 23, 1937, suggesting that the questionnaire be used as a form around which to build a self-analysis of local activities. Four main considerations to which attention was called in the questionnaire were as follows:

1. Aim or objective of Section.

2. Activities carried on by the Section to accomplish the objective.

3. Results obtained by the activities during the last 5 years.

4. Changes or additions suggested in the activities by your Section.

Chairman Timbie reported that although the time allowed was short, some 25 returns out of the possible 62 had been received in time to report to the convention, and that others were expected later. Reporting for the Sections committee at the request of Chairman Timbie, Clifford M. Foust, chairman of the Schenectady Section, summarized the information given in the 18 responses that had been received by May 28:

I. *Aim or Objective of Section.* Some 60 total aims or objectives were recognized in 18 analyses returned, although cases of similarity reduced the number of definite and differing aims to about 25. The aim or objective set forth in the AIEE Constitution, article I, section 2, was specifically recognized by a considerable number of Sections:

Its objects shall be the advancement of the theory and practice of electrical engineering and of the allied arts and sciences and the maintenance of a high professional standing among its members.

In addition the generally accepted objectives of practically all Sections may be briefly stated as follows:

To provide opportunities for workers in the field to become acquainted, to exchange ideas, to keep up to date technically, and to advance the profession to higher standards.

Further items mentioned include the following:

1. To stimulate interest in national activities of the AIEE.

2. To stimulate contributions to ELECTRICAL ENGINEERING.

3. To inform the public of progress in electrical engineering.

4. To provide a place and an opportunity to present and discuss papers.

5. To assist the student and to retain his membership in AIEE.

6. To retain among the membership those of high professional reputation.

7. To promote individual, organizational, and civic interest.

8. To discuss topics of economic interest.

9. To co-operate with other engineering societies in promoting education and other purposes.

10. To supply where required an organization for the promotion of civic interests such as a popular lecture course.

11. To create opportunities of advancement for young engineers.

It is recognized that many of these stated objectives are means, not ends, and may be regarded as but secondary aims. However, these secondary aims are frequently the guides to the daily conduct of affairs, and must therefore be in accord with the primary aims or objectives as given in the Constitution and previously quoted.

II. *Activities Carried on by the Sections To Accomplish the Objective.* The principle

activities reported under this heading include:

1. Technical lecture meetings.
2. Combined business-social meetings.
3. Prize papers or paper competitions.
4. Combined Section and Student Branch meetings.
5. Technical discussion groups.
6. Young-member discussion groups.
7. Co-operation with other engineering societies.

Some of the special activities reported to have been especially helpful to particular Sections include:

1. Popular nontechnical meetings.
2. Inspection trips.
3. News letters.
4. Weekly luncheons.
5. Technical courses (particularly electronics).
6. Educational services to schools.

III. *Results Obtained From Activities as Carried on During the Last 5 Years.* Practically all Sections express confidence that substantial progress is being made toward the desired objectives summarized under item I through the program as outlined under item II.

IV. *Changes or Additions Suggested in Activities of Individual Sections.* This critical portion of the self-analysis lends itself less readily to summarizing than the preceding 3 sections, where an extensive degree of overlapping of aims, activities, and results permitted a fairly representative summary to be prepared. Under this section, however, no such overlapping prevails; each Section has its attention fixed for the moment on one or more changes that seem valuable to it. The following enumerates most of these prospective changes and attempts some classification:

Those pertaining to organization

1. More definite plans for active participation of young members.
2. More democratic elections.
3. Admit "local" members.
4. Make activities for members only.
5. Closer co-operation with Student Branches.
6. Establish a local advisory board.

Table I. Record of Attendance of Section Delegates and Student Branch Counselors at Milwaukee Conference

Section	Delegate Name and Affiliation
Akron	A. O. Austin (A'04, F'25) manufacturing engineer, Barberton, Ohio; Section chairman 1937–38
Atlanta	J. M. Flanigen (A'22, M'25) assistant superintendent, Georgia Power Company; Section secretary 1936–38
Baltimore	R. L. Thomas (A'19, M'26) general superintendent, Pennsylvania Water and Power Company; Section chairman 1936–37
Boston	C. L. Dawes (A'12, F'35) associate professor of electrical engineering, Harvard University; Section chairman 1936–37
Central Indiana	L. E. Beck (A'29, M'37) assistant professor of electrical engineering, Purdue University
Chicago	N. C. Pearcy (A'24, M'30) electrical engineer, Public Utility Engineering and Service Corporation; Section chairman 1937–38
Cincinnati	L. R. Culver (A'22, F'35) associate professor of electrical engineering, University of Cincinnati; Section chairman 1937–38
Cleveland	F. E. Harrell (A'26, M'35) assistant chief engineer, Reliance Electric and Engineering Company; Section chairman 1937–38
Columbus	E. E. Kimberly ('34) associate professor of electrical engineering, Ohio State University; Section chairman 1936–37
Connecticut	J. A. French (M'22) research engineer, Connecticut Light and Power Company; Section chairman 1937–38
Dallas	L. E. Cook (A'25, M'35) supervisor of distribution, Texas Power and Light Company; Section chairman 1936–37
Denver	H. F. McPhail (A'19, M'27) assistant chief electrical engineer, United States Bureau of Reclamation; Section chairman 1936–37
Detroit-Ann Arbor	D. H. Baker (A'30) transmission and protection engineer, Michigan Bell Telephone Company; Section chairman 1937–38
East Tennessee	C. Hutchinson (A'36) electrical engineer, Tennessee Public Service Company; Section chairman 1936–37
Erie	J. W. Teker (A'31) engineer, General Electric Company; Section chairman 1936–37
Florida	W. Austin Smith (A'33) consulting engineer; Section chairman 1936–37
Fort Wayne	D. H. Hanson (A'31) electrical engineer, General Electric Company; Section chairman 1936–37
Houston	V. O. Clements (A'30) sales engineer, Westinghouse Electric & Manufacturing Company; Section chairman 1937–38
Iowa	F. H. McClain (M'29) associate professor of electrical engineering, Iowa State College; Section chairman 1936–37
Ithaca	R. F. Chamberlain (A'20) assistant professor of electrical engineering, Cornell University; Section chairman 1936–37
Kansas City	A. L. Maillard (M'23) Kansas City Power and Light Company; Section chairman 1936–37
Lehigh Valley	E. F. DeTurk (A'24, M'30) transmission and distribution superintendent, Metropolitan Edison Company; Section chairman 1937–38
Los Angeles	J. C. Gaylord (A'11, M'26) hydro engineer, Southern California Edison Company Ltd.; Section chairman 1936–37
Louisville	Stanley Warth (A'28, M'36) division transmission engineer, Southern Bell Telephone and Telegraph Company; Section chairman 1936–37
Lynn	R. M. Pfalzgraff (A'29) assistant engineer, General Electric Company; Section chairman 1937–38
Madison	E. D. Ayres (A'26, M'31) associate professor of electrical economics, University of Wisconsin; Section chairman 1937–38
Memphis	P. G. Cartwright (A'30) relay tester, Memphis Power and Light Company; Section chairman 1936–37
Minnesota	A. Nelson (A'28) sales engineer, Westinghouse Electric & Manufacturing Company; Section chairman 1937–38
Montana	W. A. Boyer (A'26) electrical engineer, Anaconda Copper Mining Company; Section chairman 1936–37
Nebraska	O. E. Edison (A'17, M'26) associate professor of electrical engineering, University of Nebraska; member, committee on Student Branches 1936–37
New Orleans	F. G. Frost (M'22) general superintendent, electrical department, New Orleans Public Service, Inc.; Section chairman 1937–38
New York	A. G. Oehler (A'18, F'26) editor, Simmons-Boardman Publishing Company; Section chairman 1936–37
Niagara Frontier	R. M. Darrin (A'28, M'34) in charge of sales to central station customers, Buffalo District, General Electric Company; Section chairman 1937–38
North Carolina	F. L. Moser (A'25, M'31) superintendent of maintenance, Duke Power Company; Section chairman 1932–33
Oklahoma City	E. D. Freeman (A'32, M'35) superintendent, electrical department, Oklahoma Gas and Electric Company; Section chairman 1936–37
Philadelphia	O. C. Traver (A'10, M'20) assistant designing engineer, General Electric Company; Section chairman 1936–37
Pittsburgh	J. R. MacGregor (A'23, M'29) chief engineer, Bell Telephone Company of Pennsylvania; Section chairman 1936–37
Pittsfield	A. Boyajian (A'18, F'26) technical engineer, General Electric Company; Section chairman 1937–38
Portland	C. C. Boozier (A'23) sales engineer, Westinghouse Electric & Manufacturing Company; Section secretary 1936–37
Rochester	E. H. Branson (A'15, M'35) director of engineering, research laboratory, General Railway Signal Company; Section chairman 1936–37
St. Louis	L. O. Campbell (A'20, M'29) assistant to engineer, General Electric Company; Section secretary 1934–35
San Antonio	N. B. Gussett (M'37) San Antonio Public Service Company
San Francisco	R. O. Brosemer (A'31) engineering department, General Electric Company; Section chairman 1937–38
Schenectady	C. M. Foust (A'22, M'31) General Electric Company; Section chairman 1936–37
Seattle	C. H. Hoge (A'19, M'29) assistant engineer, Puget Sound Power and Light Company
Sharon	T. H. Frankenberry (A'27, M'29) design transformer engineer, Westinghouse Electric & Manufacturing Company
Spokane	M. F. Hatch (A'33) assistant engineer, Washington Water Power Company; Section chairman 1937–38
Springfield	C. G. Veinott (A'28, M'34) design engineer, Westinghouse Electric & Manufacturing Company; Section chairman 1936–37
Syracuse	C. W. Henderson (A'20) professor of electrical engineering, Syracuse University; Student Branch counselor
Toledo	G. J. Clark (A'31) salesman, industrial division, General Electric Company
Toronto	M. J. McHenry (A'11, M'20) manager, Toronto district, Canadian General Electric Company; Section chairman 1935–36
Urbana	H. J. Reich ('32) associate professor of electrical engineering, University of Illinois; Section chairman 1936–37
Utah	C. A. Wolfrom (A'10) division manager, Utah Power and Light Company; Section chairman 1937–38
Vancouver	F. L. Code (A'27) instructor, Vancouver Technical School
Virginia	J. E. Jackson (A'26) district manager, Appalachian Electric Power Company; Section chairman 1936–37
Washington	J. F. Meyer (A'08, M'13) principal physicist, National Bureau of Standards; Section chairman 1937–38
Worcester	V. Siegfried (A'32) instructor in electrical engineering, Worcester Polytechnic Institute; Section chairman 1937–38
Chairman, Sections committee	W. H. Timbie (A'10, F'24) professor of electrical engineering, Massachusetts Institute of Technology, Cambridge

(1) (2) (3) (4)

(1) President-Elect W. H. Harrison (left) of New York, N. Y., interests Vice Chairman E. E. George of the East Tennessee Section, and Mrs. George. (2) Chairman H. S. Osborne (left) of the technical program committee, New York, N. Y., and Past-President J. B. Whitehead of Baltimore, Md., discussing a point of mutual interest. (3) Past-Presdent H. P. Charlesworth, of New York, N. Y. (4) M. G. Malti (left) of Ithaca, N. Y., and Past Vice-President W. H. Timbie (right) of Cambridge, Mass., having an interesting discussion with a third party

7. Better meeting place required.
8. Eliminate "local" members.
9. Representation on national committees.
10. Better co-operation with local engineering council.
11. Study and co-operate with ECPD on professional standing.
12. Refer applicants for admission to AIEE membership to local committee.
13. Appoint more young members to definite activities.
14. Increase number of contacts with engineers.
15. Elect chairmen of committees instead of appointing.
16. Give prizes for best membership work.

Those pertaining to meetings

1. Organize technical classes.
2. Study groups in public speaking, economics, business administration.
3. Hold meetings at other points in the Sections.
4. More inspection trips.
5. Discuss social and economic problems.
6. Take part in a monthly program with other societies.
7. Decrease number of meetings.

Those relating to papers

1. Exchange of papers in the District.
2. More national papers.
3. Begin a prize-paper contest.
4. Organize a committee to stimulate national papers.

In general these proposed changes are under consideration as means toward a more successful realization of avowed aims and objectives. Most of them have been tried in other Sections and frequently found valuable, while others have not been tried or have been unsuccessful experiments. However, local conditions, as has frequently been pointed out, call for local and particular treatment, and it is therefore desirable that each Section work out activities best fitted to its circumstances.

General Results of Self-Analysis. The 18 Section reports covered in the preceding digest are sufficient in number and of such quality as to justify the following definite conclusions concerning the analysis:

1. Each Section making an analysis has benefited by a better understanding of its own problems.
2. Through the availability of this summary, each Section can compare its own program with those of other Sections.
3. As a result of analyzing these returns, the Sections committee is in a better position to advise individual Sections concerning local problems.

Section officers are urged to communicate directly with the chairman of the Sections committee concerning any particular detail of this survey, or concerning any Section operating problem in which there may be a special interest.

Registration of Engineers Discussed at Length

The current situation regarding the registration of engineers was the subject of practically a full afternoon's discussion. As indicated in the conference program, the general discussion was preceded by 4 informal reports: The eastern viewpoint was reflected by Chairman A. G. Oehler of the New York Section; the middlewest viewpoint was reflected by N. C. Pearcy of the Chicago Section; west-coast opinion was represented by Chairman J. C. Gaylord of the Los Angeles Section; President A. M. MacCutcheon traced briefly the evolution of the subject as it has been considered by the board of directors from time to time, and spoke at some length concerning the views that he had gathered incident to his recent contacts with a majority of the Institute's Sections.

Out of the ensuing discussion and variety of opinion concerning the various questions raised, the following general conclusions seemed to emerge as representing the consensus of opinion: (*a*) that inasmuch as laws providing for the registration of engineers have been adopted in some form or other by a majority of the States, efforts should be put forth to secure more nearly uniform legislation; (*b*) that ambiguities in existing laws should be clarified, and provisions made for the proper recognition of the different professional classes of engineers.

After extensive discussion of these and other phases of the problem, and after a generous exchange of experiences and recommendations from various Section representatives and other interested members, the entire question including a verbatim transcript of the meeting was turned over to a special national committee appointed by President MacCutcheon for the purpose of studying further into the question and for making such recommendations concerning national policy as might seem desirable.

Publication Policy Considered at Length

In opening the Tuesday-afternoon conference session Chairman Timbie stated that the subject of publications was one of the 2 subjects for which a place on the conference program had been requested by a large number of Section representatives. He emphasized again that the principal objective of the discussions as scheduled was to provide an opportunity for the governing committees to learn "just exactly what the individual member wants," in this case "in the way of a publication policy."

I. M. Stein Reviews Publication Policy

Chairman I. M. Stein of the publication committee read the following report:

"During the past year your publication committee has been studying our publication policy with the idea of recommending revisions which would provide an improved publication service to our membership.

"It will be recalled that a change was made in our publication policy in 1933 in order to effect economies which were necessary in view of our drastically reduced income. The arrangement adopted at that time has accomplished its primary purpose very well, namely, a substantial reduction in expenditures, and this without making any great reduction in the publication service rendered.

"Naturally it is desirable to retain all of those economies which do not materially interfere with the maintenance of a good publication service. On the other hand, there are some defects which should be remedied as soon as we can afford to do so. The arrangement adopted in 1933 reduced publication expenditures to what appears to be the practical minimum and, hence, any important modification is almost certain to result in some increase in cost, that is, unless, in providing some new desirable feature, some other feature which has been considered desirable in the past is withdrawn.

"However, in view of the improvement in general conditions, it is likely that we can afford a modest increase in publication expenditures in order to render better service.

"Among the improvements which many of our members seem to desire are the following:

1. An increased number of high-grade general interest articles in Electrical Engineering.

(*Continued on page 1050*)

Table II. Record of Attendance of District Student Branch Counselor-Delegates

District	Delegate Name and Affiliation
1	E. M. Strong ('26) assistant professor of electrical engineering, Cornell University, Ithaca, N. Y.
2	E. O. Lange (A'19) associate professor of electrical engineering, Drexel Institute, Philadelphia, Pa.
3	H. N. Walker (A'27, M'34) assistant professor of electrical engineering, New York University, New York City
4	S. W. Anderson (A'16, F'31) professor of electrical engineering, Virginia Military Institute, Lexington
5	S. S. Attwood (A'21, M'28) associate professor of electrical engineering, University of Michigan, Ann Arbor
6	G. H. Sechrist (A'20) chairman, electrical engineering department, University of Wyoming, Laramie
7	Chester Russell (A'29, M'34) acting head, department of electrical engineering, University of New Mexico, Albuquerque
8	E. F. Peterson (A'30) professor of electrical engineering, University of Santa Clara, Santa Clara, Calif.
9	J. A. Thaler (A'03, F'13) professor of electrical engineering, Montana State College, Bozeman

Chairman, committee on Student Branches—F. Ellis Johnson (A'13, F'31) dean of college of engineering, University of Missouri, Columbia

Newly Elected AIEE National Officers

M. J. McHENRY
Vice-President

District Manager, Canadian General Electric Company, Toronto, Ont.

E. D. WOOD
Vice-President

General Superintendent, Louisville Gas and Electric Company, Louisville, Ky.

I. M. STEIN
Vice-President

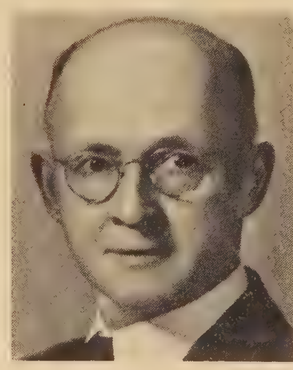
Director of Research, Leeds and Northrup Company, Philadelphia, Pa.

L. N. McCLELLAN
Vice-President

Chief Electrical Engineer, United States Bureau of Reclamation, Denver, Colo.

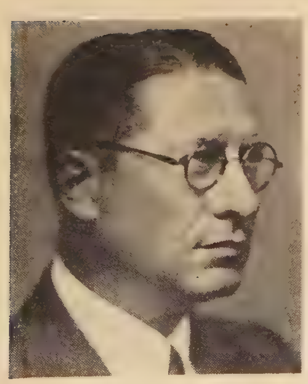
W. H. HARRISON
President

Assistant Vice-President, Department of Engineering and Operation, American Telephone and Telegraph Company, New York, N. Y.



J. P. JOLLYMAN
Vice-President

Chief of Division of Hydroelectric and Transmission Engineering, Pacific Gas and Electric Company, San Francisco, Calif.



C. R. BEARDSLEY
Director

General Superintendent of Distribution Construction, Brooklyn Edison Company, Brooklyn, N. Y.

VANNEVAR BUSH
Director

Vice-President, and Dean of School of Engineering, Massachusetts Institute of Technology, Cambridge

F. H. LANE
Director

Manager, Engineering Division, Public Utility Engineering and Service Corporation, Chicago, Ill.

(1) (2) (3) (4) (5)

(1) Chairman I. Melville Stein of the publication committee, Philadelphia, Pa., and President A. M. MacCutcheon enjoying a good joke. (2) Past Chairman P. S. Biegler (left) of the Los Angeles Section. (3) Past Chairman F. R. Innes (right) of the Chicago Section. (4) Chairman J. C. Gaylord (left) of the Los Angeles Section interests E. L. Bettannier of Pasadena, Calif., and E. R. Hedrick of Los Angeles. (5) N. R. Stansel (left) of Schenectady, N. Y., past chairman of the committee on electrochemistry and electrometallurgy, conversing with M. R. Winkler of Chicago, Ill.

2. The restoration of some procedure for making available preprints of technical-program papers.

"Although the point has not been raised by many individual members, there is one important defect in the present publication policy which is quite evident to the publication committee and has been stressed by some outstanding Institute members who have clearly in mind the broad general interests of the Institute. This point has to do with the character of our annual bound volume called the TRANSACTIONS. With the adoption of the 1933 publication policy, the term TRANSACTIONS lost all real significance, as that volume then became nothing more than the annual bound volume of ELECTRICAL ENGINEERING. It seems clear that the broad general interests of the Institute would be served best if the earlier character of TRANSACTIONS were restored by publishing in TRANSACTIONS only those technical papers which mark a real advance in the electrical-engineering art. Probably this requirement could be met practically by publishing in TRANSACTIONS only those papers which have been approved by the technical program committee and which are otherwise acceptable to the publication committee.

"In keeping with these thoughts, the publication committee, at its meeting in January 1937, considered certain modifications in our publication policy. Several of these were approved by the committee and were presented to the board of directors, where they were also approved. Among these was one which is of general interest to our membership and had to do with providing a larger number of high-grade general-interest articles in ELECTRICAL ENGINEERING. The board of directors approved an increase in our publication budget in order to accomplish this, and those members who read ELECTRICAL ENGINEERING regularly have probably noticed an increased amount of such material, some dealing with economic and social subjects.

"The matters of providing preprints and of restoring the character of TRANSACTIONS were not included in recommendations to the board of directors, as it was felt that these features should have further discussion in the technical program committee and at this conference. The technical program committee referred these matters to a special subcommittee, which has made a real study of the matter and has arrived at tentative conclusions, some of which will be presented by the next speaker.

"The study made by this subcommittee has brought into the picture one feature not included in the publication committee's previous study, namely, the desirability of reducing the time between the submission of a paper to the technical program committee and its presentation at a meeting. This point will be discussed more fully by the next speaker and is mentioned here only because it ties in very closely with the matter of providing preprints. Specifically, the subcommittee's tentative recommendation is that the requirement of prepublication in ELECTRICAL ENGINEERING should be withdrawn and that the author's manuscript should be reproduced by the offset printing process so as to provide quite promptly at least a sufficient number of preliminary preprints to facilitate discussion at meetings. The subcommitee's tentative conclusions are in agreement with the publication committee's conclusions that the former character of TRANSACTIONS should be restored and that the contents of ELECTRICAL ENGINEERING should reflect the wishes of our membership in the matter of providing a large number of general-interest articles.

"It is apparent that there would be considerable opposition to making radical changes in our publication policy and procedures, and fortunately it would seem possible to provide the additional desirable features without making radical changes and with only a modest increase in publication expense. This might be accomplished about as follows:

1. Remove the requirement for the prepublication of technical-program papers in ELECTRICAL ENGINEERING and provide preliminary preprint copies of the author's manuscript by means of the offset printing process.

2. After technical-program papers have been presented, submit them to critical review and revision by the appropriate technical committees at the same time the discussion is reviewed, and then publish the paper and its associated discussion in a segregated section of ELECTRICAL ENGINEERING, the segregated section having appropriate page numbers to permit making an overrun for binding in TRANSACTIONS. The additional material in ELECTRICAL ENGINEERING, if bound at all, would be bound in a separate volume, carrying the title ELECTRICAL ENGINEERING.

3. Continue to provide a substantial number of general interest articles of a technical, economic, and social nature in each issue of ELECTRICAL ENGINEERING.

"It is not the intention of the publication committee to present at this time very definite recommendations, nor are we expecting this conference to pass any formal resolution with regard to publication policy, although, of course, this conference is at liberty to take any action that it pleases. According to our by-laws, it is the function of the publication committee to formulate a publication policy and submit it to the board of directors for approval. In formulating a publication policy, your publication committee desires to have the benefit of your advice and criticism and that is the purpose of presenting the matter here. It is hoped that you will discuss the matter freely and fully, stating just as informally as you like any dissatisfaction which you may have with the present publication policy and such changes as you may wish to have incorporated in our publication policy."

PUBLICATION RECOMMENDATIONS FROM TECHNICAL PROGRAM COMMITTEE

Reporting for a special subcommittee appointed by the technical program committee, Director W. B. Kouwenhoven of Baltimore, Md., presented the following abstracts of recommendations endorsed by the technical program committee:

"The technical program committee, at its January 25 meeting, authorized the appointment of a special subcommittee to review our policy in regard to the handling of Institute technical papers and to report back to them any changes that were thought advisable." [Subcommittee: chairman, R. N. Conwell, past-chairman, technical program committee; J. W. Barker, past-chairman committee on production and application of light; and W. B. Kouwenhoven, director and past vice-president.]

"The problem of Institute programs and their proper handling involves not only the technical papers but also ELECTRICAL ENGINEERING, our publication, and TRANSACTIONS. As we see it, there are 4 or possibly 5 requirements that ought to be met. They are:

1. A minimum of elapsed time should pass between the preparation and presentation of a paper.

2. We should provide preprints of technical papers.

3. The TRANSACTIONS should carry high-quality contributions.

4. Development of ELECTRICAL ENGINEERING into a general-interest magazine or, as Mr. Stein put it, provision for making ELECTRICAL ENGINEERING a "balanced publication," containing a substantial number of general-interest articles in each issue.

"This subcommittee has held several meetings, and at the April 2 meeting of the technical program committee it presented a preliminary report making a few suggestions and asking for discussion. There was a gratifying response to our request, and, as a result of this discussion and further work, we submitted on June 8, to the technical program committee, a progress report suggesting 7 changes in our methods of handling technical papers and publications. In making these suggestions we had in mind 3 things:

1. To provide preprints for use at meetings.

2. Taking from ELECTRICAL ENGINEERING the necessity of publishing all technical papers submitted.

3. Making the TRANSACTIONS the principal place in which technical papers would be found.

Those suggestions are as follows:

1. The author prepares his manuscript in the

Table III. Record of Attendance of District Secretaries

District	Name and Affiliation
1	R. G. Lorraine (A'29, M'36) central station dept., General Electric Co.
2	H. A. Dambly (A'24, M'30) asst.engr., special investigation and test div., Philadelphia Elec. Co.
5	A. G. Dewars (A'17, M'27) system planning engr., Northern States Pwr. Co.
7	L. C. Starbird (A'32, M'35) transmission and protection engr., Southwestern Bell Tel. Co.
8	Fred Garrison (A'22, M'29) commercial engr., General Elec. Co.
9	S. E. Caldwell (A'29) engr., Pacific Pwr. & Lt. Co.

form in which he wishes to present it and sends it to headquarters.

2. Manuscripts to be printed directly from the original immediately upon arrival, about 20 or 25 copies run off and the plates retained.

3. The editor of Electrical Engineering receives his copy. The secretary of the technical program committee distributes the balance of the copies to the proper technical committee for review.

4. Review, grade, and recommend for or against presentation. They do no editing for the present, but retain their copies and notes.

5. If recommended for presentation, sufficient preprints are run off for distribution at the meeting. The editor of Electrical Engineering may at this point elect to run all or part of the paper as a general-interest article, if it suits his purpose.

6. Paper is presented and discussed.

7. Paper and discussion then edited by the proper technical committee, and recommended for inclusion in the Transactions or discarded.

"These changes, if carried out, will tend to make Electrical Engineering a general-interest magazine. In the main, technical papers will appear in the Transactions only. They will, however, be available in preprint form.

"We are hoping that at this meeting of the Section delegates and those others present, there will be considerable discussion of these proposals. Perhaps it may be that our membership is satisfied with the present arrangement; perhaps you desire changes. Not only do we want the changes and suggestions that you have here, but others that occur to you later. We would appreciate it very much if you would write Mr. H. S. Osborne (chairman of the technical program committee) and send him any suggestions that you may have."

Other Phases of Problem Discussed

In discussing various questions raised with respect to publication procedures and related economics, Editor G. Ross Henninger pointed out that the so-called unified publication plan that has been followed for the past 3 years involved a minimum of cost for the amount of material published, and that any modification or broadening of any of the several phases of the Institute's publication service would require a commensurate increase in publication appropriation. Various phases of the publication problem were discussed at length by many interested delegates present.

To provide a means for expressing the opinion of members and delegates present in such a way as to guide the publication committee in formulating its policy modification, a hand vote was taken on the following questions, with the results as noted:

1. "Is our present publication policy generally satisfactory?" Yes, 16; No, 38.

2. "Shall the present general policy be continued, but provisions made for the printing of more material by using the present 'easy reading' type for only the summary of each paper, and smaller type for descriptive and technical portions?" Yes, 24; No, 36.

3. "Should Electrical Engineering be 'popularized,' that is, have more general interest articles?" Yes, unanimous.

4. "Should preprints of technical papers be supplied at conventions, followed by publication in Transactions?" Yes, 48; No, 5.

5. "Should the material of Transactions be completely divorced from that of Electrical Engineering resulting in effect in 2 separate periodicals, one of a general nature, and one technical?" Yes, 25; No, 40.

6. "Should Transactions be split into sections according to subject matter so that each member can subscribe for individual sections?" Yes, 1; No, practically unanimous.

No formal action was taken by the group, it being the expressed opinion of Chairman Stein of the publication committee that the spoken character of the discussion had given to the several members of his committee present sufficient insight into the problem to enable the committee to proceed in due course with its disposition.

Vice-President C. F. Harding of Lafayette, Ind., and Mrs. K. L. Hansen of Milwaukee

For an hour or so prior to the closing of the conference, there was an active discussion of, and exchange of information and operating experiences concerning various operating problems confronting the Sections, such as the type of rooms provided for Section meetings and the cost thereof, and policies and procedures prevailing with respect to local members.

Counsellor-Delegate Session

Under the leadership of Chairman F. Ellis Johnson of the committee on Student Branches, a large group particularly interested in that phase of Institute work spent all of Monday afternoon plus a dinner session Wednesday evening, in discussing various matters pertaining to Branch activity, and in exchanging experiences. These discussions concerned membership activities of the Branches, style and organization of programs, procedure in the election of officers, degree of stimulation of student participation in the preparation of technical papers, ways of developing leadership, the promotion of professional contact for student engineers, the relationship between the faculty and the Student Branches, and various suggestions concerning ways in which the Institute might aid in the development of Branch activity. No formal actions were taken nor resolutions adopted.

Training for Marketing Industrial Products

A course of training in marketing technical products is being pursued by a group of young technical graduates employed by the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., under the leadership of Bernard Lester (A'06, M'13) assistant industrial sales manager of the company and lecturer at the University of Pittsburgh. The group, which consists of 25 men selected by their department heads, is taking the course as part of the University of Pittsburgh-Westinghouse graduate study program; this was described in the paper "The Pitt-Westinghouse Graduate Program" by H. E. Dyche and R. E. Hellmund in Electrical Engineering, volume 53, January 1934, pages 103–08.

The days of the breezy, smart, slap-stick salesman have gone, according to Mr. Lester. Engineering selling today is a serious matter and although personality in the individual can add much to his success, the man who will attain a sound and continued success is the one who knows the technique of the product to be sold, the character of the market to be met, and above all, who is able to interest himself in his customer's problems and their solution. By study and application of principles the course aims to develop such men.

Primer of Electric Service Costs. A 94-page book comprising a discussion of utility problems from the standpoint primarily of utility costs has been written by Roy Page (A'11, M'21) vice-president and general manager of the Nebraska Power Company, Omaha, and published by Harper and Brothers, New York, N. Y. The book is intended primarily for educational use by public-utility employees, but according to the publisher also supplies material for all who are interested in public utility economics from any point of view. The author has been associated with the Nebraska Power Company for nearly 20 years, and formerly was employed by the Southern Pacific Company and the Pacific Telephone and Telegraph Company.

Technical Conferences Held During Summer Convention at Milwaukee

A TYPE of meeting introduced at the 1935 summer convention at Ithaca, N. Y., and one that has proved most popular and effective, is the informal "technical conference." These conferences have been developed primarily to serve the younger members of the Institute and the technical specialists. Definitely on the program schedule at Milwaukee were 2 such technical conferences, one on field problems, and one on electrical apparatus for 3-phase arc furnaces. In addition, several technical subcommittee and other discussion-group sessions developed spontaneously during the course of convention week; these included meetings of:

1. Transformer subcommittee.

2. Joint subcommittee on insulation strength of electrical equipment.

3. Sectional committee on transformers.

4. Subcommittee on sphere-gap calibration and impulse-voltage measurements.

Available reports are given in the following paragraphs.

Field Problems

By Ernst Weber, Chairman

The program of this meeting, which was attended by more than 50 people, was arranged as follows:

1. Introduction: The Field Concept in Physics and Engineering.

2. Topics:

a. Graphical Field Plotting—Special Applications to Magnetic Fields.

b. Analytical Solutions of Fields—Special Applications to Heat Problems.

c. Conformal Representation—Special Applications to Electric Fields.

d. Experimental Methods of Field Exploration—Special Applications to Hydrodynamics.

The introduction (by Chairman Weber) showed the evolution of the field concept from Newton to Maxwell in a historical survey. From the electromagnetic field the concept of continuous action then penetrated all other branches of applied physics; tables were shown to illustrate the common basis of mathematical treatment in all instances where the field concepts can be applied, such as electricity, gravitation, electron statics, magnetics, heat, electroconduction, and hydrodynamics.

To illustrate the most advanced experimental means for field exploration, films were shown by courtesy of the Institute of Aeronautical Sciences (RCA Building, New York, N. Y.) depicting experimental research in the laboratories of England and Germany. Various methods of making visible the flow of air past objects such as plates, wing profiles, and various attachments illustrated vividly the *lines of flow.*

A. L. Oklund (Marquette University, Milwaukee) described the adaptation of the electrolytic trough to obtain certain 3-dimensional field distributions important in designs of magnets. Sterling Beckwith (Allis-Chalmers, Milwaukee) delivered a discussion prepared by O. K. Marti (also Allis-Chalmers) describing the field distribution in rectifiers during the initiation of the arc.

Graphical methods to obtain field distribution were outlined by Doctor H. Poritsky (General Electric). Application of rotational symmetrical field plotting to the design of magnet poles, and for obtaining the stressed distribution in shafts under torsional forces was explained and illustrated. Professor H. B. Palmer (University of Colorado, Boulder) exhibited a motion-picture prepared under his direction, which gave the electric and magnetic field distribution about a 3-phase transmission line arranged in an equilateral triangle. This pictorial demonstration was received with great enthusiasm.

The treatment of 2-dimensional fields by conformal mapping was outlined by Chairman Weber. After a brief review of the theory of complex functions, the application of conformal representation to electron-tube problems was shown. The power of the method of transforming the boundary by means of complex functions was illustrated by an edge-correction problem, by profiling of airplane wings, and by problems in electron "guns." An application of the Schwartz-Christoffel theorem for the transformation of polygonal boundaries was given by Professor Palmer, who described the field about a capacitor.

Professor M. G. Malti (Cornell University, Ithaca, N. Y.) emphasized the difficulty of depicting the field in more complex arrangements, but Doctor Poritsky explained that at least approximate solutions always can be given by a proper combination of graphical and analytical methods. Professor Edward Bennett (University of Wisconsin, Madison) stressed the value of field methods in connection with research on antenna fields conducted under his supervision. Professor C. L. Dawes (Massachusetts Institute of Technology, Cambridge) emphasized the value of conformal representation in teaching electrostatics where time and labor can be saved to a considerable extent.

Informal group discussions continued after the conference session was formally closed.

Electrical Apparatus for 3-Phase Arc Furnaces

By N. R. Stansel, Chairman

The first technical conference on electrical apparatus for 3-phase arc furnaces, sponsored by the AIEE committee on electrochemistry and electrometallurgy, was considered by all present to be highly successful, and by its result proved conclusively the value of such an informal conference as a means of disseminating information of use and interest to the engineers concerned, and of provoking a lively discussion on the subject under consideration. More than 100 persons attended.

As arranged by the chairman of the conference, N. R. Stansel (General Electric, Schenectady, N. Y.) the program provided for several brief and informal talks by engineers familiar with various aspects of arc-furnace equipment in which the user was particularly interested. Preceding these discussions, an illustrated talk was given by Samuel Arnold III (American Bridge Company, Pittsburgh, Pa.) concerning modern electrical equipment for arc furnaces.

The kilovolt-amperes required for arc furnaces in accordance with their dimensions and tonnage ratings was discussed by Frank Brooke (Swindell-Dressler Corporation, Pittsburgh, Pa.) and provoked some general comment.

Growth of the multivoltage arrangement for secondary voltages was outlined briefly by C. C. Levy (Westinghouse, East Pittsburgh, Pa.).

A lively discussion was aroused by F. V. Andreae (Ohio Ferro Alloys Corporation, Philo) by his comments on reactance, particularly with regard to the methods of specifying reactance in furnace circuits, and the effects of reactance.

In discussing regulations, F. E. Ackley (General Electric, Schenectady, N. Y.) emphasized some fundamental points in regulation with respect to maximum power inputs to a furnace, that are not always understood by furnace operators. He also described a newly developed electrode regulator.

Remarks concerning electrical protection for furnace circuits made by E. L. McClure (Milwaukee Electric Railway and Light Company) stressed the desirability of using service breakers for short-circuit protection independent of the furnace breaker itself, so as to avoid the problem of having an expensive circuit breaker especially designed for frequent operations.

A résumé of interesting analytical work done by the Detroit Edison Company to determine the size of sub-stations required to feed a given furnace load under prescribed conditions of maximum voltage variation, and what could be done when these prescribed conditions could not be met, was given in an illustrated discussion by L. W. Clark of that company.

ASTM Awards Dudley Medal. The American Society for Testing Materials has awarded the Dudley Medal for 1937 to W. H. Swanger, chief of the section of mechanical metallurgy and assistant chief of the division of metallurgy, and G. F. Wohlgemuth, associate metallurgist, of the National Bureau of Standards. The medal, which commemorates the name of the first ASTM president (1902–09), is awarded for the paper presented at the preceding annual meeting that is of outstanding merit and constitutes an original contribution on research in engineering materials. The winning paper, "Failure of Heat-Treated Steel Wire in Cables of the Mt. Hope, R. I., Suspension Bridge," describes the extensive work undertaken at the National Bureau of Standards to determine the causes of the failure.

Last Call for the Pacific Coast Convention

THE Spokane Section extends a cordial invitation to members of the AIEE and their guests to attend the Pacific Coast convention in that city, August 31–September 3, 1937. As announced in the July issue, convention headquarters will be in the Davenport Hotel. A technical program has been arranged with papers on a wide variety of subjects, which will be presented by well-known Institute members. Social and recreational activities include a reception and dance, banquet, and golf; and a special program has been arranged for women guests. Inspection trips will be provided to points of interest.

The excellent possibilities for recreation and relaxation afforded by Spokane and nearby territory should induce many members and their families and guests to spend a few extra days in the city or at nearby lakes and resorts. There will be ample opportunity to use fishing tackle and golf clubs.

Program

The tentative program published in Electrical Engineering for July, page 911, is now the final program, with the following changes: The subject "Lighting the San Francisco-Oakland Bay Bridge" will be given as an address by C. R. Davis, and will not be published in advance. The sports committee has found it impossible to hold the golf competition on Wednesday afternoon, as originally planned. Therefore, the golf and banquet will be held on Thursday afternoon and evening, respectively, and the session on electrical machinery and the conference on electric house heating have been transferred to Wednesday afternoon and evening, respectively.

Recreation

The golf tournament will be held on one of the several beautiful courses in Spokane. Arrangements may be made for members and guests to play at other times when desired.

Competition for the John B. Fisken Cup will be medal play on handicap in foursomes and will be open to members of the Districts 8 and 9 only. This perpetual trophy cup was donated by the electric utilities of the District 9 some 25 years ago, and competition for it has been very keen each year. Competition for a number of other golf prizes will be open to members and guests.

Excellent facilities for tennis playing are available within the city. Swimming, boating, and fishing may be enjoyed at any one of the many lakes and streams within a short distance of Spokane.

Entertainment

On the first evening of the convention a reception and informal dance will be held in the headquarters hotel. This will provide opportunity for all to meet other delegates and officers, renew old friendships, and make other contacts.

The convention banquet and presentation of golf prizes will be on the third evening of the program. A number of interesting activities have been arranged for the women.

Women's Program

The women's program committee, Mrs. L. R. Gamble, chairman, has arranged a number of parties in addition to the reception and dance and the banquet. These parties include a scenic trip through the home and civic gardens of Spokane, followed by an afternoon tea, putting and approaching contests for a number of prizes, a musical tea, and a luncheon and bridge tournament.

The many fine home gardens in Spokane will be an added attraction. The inspection trips also will hold the interest of many of the women guests.

Inspection Trips

Probably of interest to the greatest number of members will be the inspection trip to the Grand Coulee Dam area. Construction work on the dam is going ahead rapidly and it is probable that at the time of the convention the entire foundation will be in place. At the present time the Columbia River has been diverted from the original channel and is flowing over some of the foundation blocks. The trip will include the model engineers' town, the contractor's electrically heated construction camp at Mason City and a ride through the several boom towns adjacent to the workings.

The inspection trip to the Coeur-d'Alene Mining District is of great scenic value, the road following the shore of Lake Coeur d'Alene to Wolf Lodge Bay and along the route of the Captain John Mullan military road through Fourth of July Canyon. In this area are found such great silver and lead producers as the Bunker Hill and Sullivan, the Hecla, the Morning, and the Sunshine mines. In Government Gulch is located one of the world's largest electrolytic zinc plants for the treatment of zinc ores. This plant is now being enlarged.

Special arrangements may be made for additional trips to nearby points of interest including the following: Long Lake and Little Falls hydroelectric plants of the Washington Water Power Company; Up-River hydroelectric plant of the City of Spokane equipped with Kaplan automatic adjustable-blade turbines; Clearwater electrified lumber mill at Lewiston; Inland Empire paper mill in Spokane; KHQ radio tower, tallest unguyed tower (828 feet) in the United States; and Comstock Park and Swimming Pool, Spokane.

Joint Session With Radio Engineers

The Pacific Coast meeting of the Institute of Radio Engineers will be held in Spokane, September 1 and 2, concurrently with the AIEE convention and in the same hotel. Although the meetings of the IRE and the AIEE will be conducted separately, members of either organization will be welcome at the technical sessions of the other group. As previously announced, a joint session is planned for presentation of papers of interest to members of both institutes.

In addition, the inspection of Spokane's 4 broadcasting stations arranged by the IRE will be interesting to AIEE members who have not previously witnessed a broadcast.

Hotels and Registration

All members who have received the advance registration card and who plan to attend the convention are urged to co-operate by immediately filling in and mailing the card, if they have not already done so. There is no registration fee for members or their immediate families or Enrolled Students. Nonmembers will be charged a registration fee of $2.

This card contains space for requesting hotel reservations. It is extremely important that this part of the card be filled out, because all available accommodations are expected to be taken during the convention. First and second choice should be given. Members who have not received an advance registration card and who plan to attend the convention should write promptly to D. H. Olney, chairman of the registration committee, care of Washington Water Power Company, Spokane, Wash., indicating the number of reservations desired, first and second choice, and the rate.

Rates in some of the leading Spokane hotels are:

Hotel	Room for 1	Room for 2
Davenport (Headquarters)	$2.50–$4.00	$4.00–$15.00
Spokane	$2.00–$4.00	$3.00– $5.00
Desert	$2.50–$4.00	$3.00– $5.00
Coeur d'Alene	$2.00–$4.00	$3.00– $5.00

Members should register upon arrival at the Davenport Hotel, official headquarters; registration will begin at 9:00 a.m., August 31.

Student Activities

Besides the regular student conferences, the program includes 2 student technical sessions. Students will be welcome at all convention activities, including technical sessions, entertainment, and inspection trips. It is the hope of the Spokane Section that there will be full participation on the part of student delegates.

Special arrangements are being made for student housing facilities whereby students may have accommodations for $1.00 per night. Splendid auto camps are available for those who wish to use them. In sending in advance registration cards students should note the type and approximate price of accommodations required so that arrangements can be made in advance. They should also indicate whether transportation is desired for either or both of the major inspection trips.

Divergent Views Expressed at Sessions on Institute Activities

Discussions embracing widely divergent views featured the 2 general sessions on "Institute activities" held during the AIEE 1937 summer convention under auspices of the special committee on Institute activities appointed early in the year by President MacCutcheon. The first session was held on Wednesday morning, June 23, immediately following the presentation of the address "The Engineer in a Changing World" by Doctor Ralph E. Flanders (published elsewhere in this issue). The second session was held Thursday afternoon, June 24. These sessions were organized under the general chairmanship of H. S. Osborne, chairman of the committee; Director L. W. W. Morrow, and Past-President D. C. Jackson, respectively, presided at the 2 sessions.

At the first session, prepared discussions were presented by the following: Past-President A. W. Berresford (read by Past Vice-President G. G. Post); L. A. Doggett, past chairman of the committees on education and Student Branches; J. L. Hamilton, chairman of the committee on electrical machinery; F. R. Innes, past chairman of the Chicago Section; Vice-President Mark Eldredge; and Past-President J. B. Whitehead. During the second session, various interested members presented informal discussions from the floor. For the benefit of Institute members who did not attend the convention, full texts of the prepared discussions are published here.

Institute Programs

By A. W. Berresford

My understanding of the purpose of this session is to obtain opinion as to the direction and degree in which Institute programs (and in "programs" I include activities) may profitably be extended.

In any such consideration one's thought reverts almost instinctively to social and economic problems. The years since 1929 have stressed them in degree unprecedented in the history of the Institute and many of them involve elements with which the engineer is familiar. Under these conditions nothing is more natural than that question should arise as to whether advantage would accrue to the Institute as a national body, and to its members as individuals, if consideration of and action on these public questions were accepted as an appropriate function.

Briefly stated, the objects of the Institute are the advancement of the theory and practice of electrical engineering and the maintenance of a high professional standing among its members. That it has achieved a notable accomplishment in its more than 50 years of life, and largely through adherence to these constitutional provisions, will, I believe, be generally conceded. To depart from them calls therefore for serious consideration. On the other hand, if actual advantage to the membership resides in such departure, or if the opportunity for the rendering of a real public service is presented, there should be no hesitancy. It may possibly be that some of the proposals of which I have heard could, by interpretation, be included within the present language of the Constitution, but this seems immaterial. The decision to undertake new activities is the important factor, not the question of whether or not the Constitution must be changed to permit.

It seems to me that there can be no doubt of the desirability of planned and intelligently directed discussion of these matters of public concern by the Institute membership. If no more were accomplished than the inevitably resultant self-education in the pertinent conditions, and the application of engineer thinking thereto, there would be ample warrant for the time and effort expended. If in addition the solutions evolved were of such nature and importance as to influence the thinking of other parties in interest, a definite public service would be rendered.

In my belief, however, if there is to be such practical accomplishment, the activity must begin and, at least for some years, be prosecuted locally. Only in localities can there be first-hand individual contact with the problems involved and really intelligent evaluation of all the elements which affect the ultimate decision. Moreover, an incentive to continuing interest and effective action will be needed, and this is better generated and maintained when individual welfare is directly affected than when the problems partake more of the abstract.

Such organization has had definite influence in public affairs in many places in matters involving engineering, and there is no reason for assuming other than equal influence in social and economic problems; granting only an equal intelligence, understanding, and application.

A notable instance is present, curiously enough, in the city in which we are convening. The Engineers' Society of Milwaukee, in which all of the local sections of the Founder Societies are affiliated, has for many years considered each public proposal which carried engineering content and has formulated and expressed its opinion thereon. The value of that opinion has come to such recognition that in many instances—if not in every one—the city authorities have requested it and have acted only after its receipt. In many cases it has been determinative.

Here then is one way in which both the members and the public can be advantaged by engineer consideration of these questions. If such an effort were instituted in as many as possible of the political divisions and subdivisions of the country, can there be doubt of a rapidly widening public appreciation of the engineer and of growing national prestige and recognition?

On the other hand, frankly, I doubt the possibility of directly exercising a national influence save through the foregoing procedure. The obstacles lie, not in the successful evolution of solutions, but in the securing of their adoption by the other parties in interest. Usually these are composed of people who are comparatively unskilled in the specific subject, and to whom it is of relative rather than primary importance. This would not be the case if the engineer were politically significant. But he is not. He casts perhaps 200 thousand votes out of a total of 40 to 45 million.

Unless the proposal or solution he offers is so novel and forthright as to acquire immediately "head-line" prominence (and the improbability of this is evident) the engineer alone can do little toward forwarding enactment.

It is a political axiom that the public seldom weighs the facts—that it responds only to an appeal to the emotions or the pocketbook. It is my own belief that action is finally based not on the quality of thinking, but on the quantity. Only through allying himself with others can the engineer obtain the necessary quantity, and he will succeed in so doing only in the degree that self interest is evidently absent. He will be welcomed as a consultant and adviser, but will attain prominent participation only if his individual personal qualifications indicate it.

These qualifications will, necessarily and rightly, be exterior to his purely engineering attainment. They will involve political vision, administrative experience and diplomacy in operation much more than they will the technical aspects. The economist may be necessary to the solution and the engineer valuable in making it effective and practical, but its acceptance will demand the methods and experience of the politician.

Even more will these conditions apply in any effort to locate an engineer in prominent relation for the reason that he is an engineer, and that the functions to be performed are basically engineering. Again the demand will be for general qualification rather than specifically technical ones.

If I am right in the foregoing, does there lie any advantage to either the Institute or its membership in including in its national program activities which promise so little of success through its own efforts? How much of real effect in a national, social, or economic situation would be a statement of Institute opinion unless pressed by political activity and through political alliances? And if these are employed may not the resultant disadvantages quite outweigh the gains? In such a relation the Institute must anticipate being classed with those organizations which exist for material ends and may well be obliged to sacrifice some portion at least of its present nonprofit status with its accompanying advantages. Decision should be reached neither hastily nor lightly.

Institute Activities

By J. L. Hamilton

I think it will be generally agreed that during the last 50 years the Institute has served its purpose and has done a splendid job. This period has been one of technological development, and the Institute has fostered that line of work to a remarkable degree. A discussion yesterday showed that we have not reached 100-per cent perfection; we never will, but by and large a very good job has been done.

We seem now to be living in a new world, a world that is moving more rapidly than

any of us has seen or observed before, and we naturally are wondering what we are to do about it and what part we should take as engineers. We seem to have reached the inquiry stage as to what is going on and how we are going to fit into this developing picture. First, in any problem there is the will to do and the need of doing, and second, is the ability to carry out that will. It would seem that we have reached the stage where there is a will to do something about it, and that is most encouraging.

President MacCutcheon, you will recall, on Monday morning outlined his work of the year, and particularly his visits to all the sections of the country, and he brought to us a summary of the messages which he received from the crossroads, if you please. I consider that message of special significance to us in connection with the subject we are discussing here now.

In the East a few weeks ago I heard a very profound discussion by profound thinkers, or at least as profound as we have in the country. It was on the success that the New Deal has had; and, whether we are New Dealers or not is beside the point, the New Dealers do know what is going on at the crossroads, not only at *some* of the crossroads but at *all* of the crossroads, and they have the ability to interpret and put into words what is being discussed at the crossroads.

To my mind the important thing before this Institute is the matter of procedure. Do we want a planned economy in the Institute? Do we want our present committees, as efficient as they may be, and our board of directors to shoulder all the problems? Is it fair? Do we not want to get the crossroads working and get this information correlated?

I recently heard a very splendid executive on business reorganization and rejuvenation make this rather interesting statement. He said: "If you want to know how to sell more goods, the chances are you cannot pull it out of your own gray matter entirely. Call in your salesmen from the field. Get them around the table. Have them tell you how to sell more goods. They can tell you more in a half-day discussion than you and your staff can develop in months and months of effort."

Can we not take a cue, therefore, from what efficient business men have found true in this respect? Can we not organize so as to get the crossroads working and get their views reflected and incorporated in what we want to do, to a greater extent than at present? Some of the matters that have been discussed by Doctor Bush and Doctor Flanders and others are certainly right along this line. They have indicated that we should have the will to carry out some of these things. Here we are suggesting one possible way of fulfilling that will by getting all of our membership to work.

In the Army—as you know there is perhaps the oldest type of organization we have—we have what is called the staff and the line organization—one to plan and one to carry out. As we sense it, do we not have a splendid line organization? Imperfect though it is, it has done a splendid job. Perhaps our problem now is to develop more of a staff organization, an organization to pick up what is being thought at the crossroads and translate it into policies for our line organization to execute; and will not such a program as this be very beneficial in helping us to our goal, that is, to know more about commercial engineering, if you please, to know more about management engineering, more about executive engineering, more about government, and more about our 2 newest sciences of which we are still profoundly ignorant, namely, economics and psychology?

Institute Publications

By L. A. Doggett

Dean Potter entitled his 1933 presidential address before the American Society of Mechanical Engineers, "Whither Engineering?" In the present article a brief survey of the publications of the American Institute of Electrical Engineers has been made in order to describe their course to date and their present status. Such a study is essentially a study of both the meetings and the publications of the society because the published matter closely reflects the whole activity of the Institute. In short, "whither publications?" or "whither Institute activities?" means approximately the same thing.

Historical Survey

The publications of the AIEE from 1884 to 1902 reveal that the membership in that period was almost wholly interested in technical matters. Between 1902 and 1911 the same situation existed except for 5 papers on the conservation of national resources and a paper by Henry Floy on "The Engineer's Activity in Public Affairs, Public Utility Commission, Franchise, Valuations." In this period a code of ethics was initiated and later adopted.

From 1911 to 1917 considerable activity occurred in the discussion of matters of public interest and of economic content. For example:

June 1910: Conservation of Water Powers, L. B. Stillwell
June 1911: Depreciation, Henry Floy
August 1911 : Electrical Engineers and the Public, D. C. Jackson
September 1911: Appraisals, H. M. Byllesby
December 1911: Report on Water Power Development
Public Policy Committee
June 1914: Evolution of the Institute, C. O. Mailloux
January 1915: Rate System, O. B. Goldman
January 1915: Control of Public Utilities, F. G. Baum
July 1915: Class Rates, F. G. Baum
September 1915: Inventories and Appraisals, C. L. Cory and others
October 1915: Rates, P. M. Lincoln
October 1915: Public Utility Management, P. J. Kealy
February 1916: Municipal Operation, A. G. Christie
April 1916: Water Power Development, G. Dunn
November 1916: Inventory and Appraisal, P. Betts
November 1916: Continuous Inventories, H. E. Carver
November 1916: Growth and Depreciation, J. Loebenstein

From 1918 to 1937 papers of economic content and papers dealing with public questions have been almost negligible in number. From time to time, however, an occasional president of the Institute has dealt with public questions in his presidential address. In the last few years among the "Letters to the Editor" the membership has shown a very decided tendency to think more and write more on social and economic questions.

The historical picture is one of continuous and almost complete devotion to technical subjects except in the 1911–17 period. Thus for over 50 years the Institute has preserved its policy of "scholarly isolation." Within the bounds of this single objective the publications of the AIEE present a record of technical accomplishment of which the members can well be proud.

Present Condition

In the last 5 or 10 years the answer to "whither publications?" is fairly specifically answered by the code of the AIEE technical program committee. This committee is a development of the old meetings and papers committee. Although the code of this committee has never been adopted in the sense that the code of ethics was adopted, it does represent the outgrowth of a long period of experience both in the old and in the new committee. This code includes a 15-item list of "acceptable subject matter" and a 4-paragraph list of "subjects not suitable for Institute presentation." Without taking the time to quote these in detail, the intent was primarily to fix the metes and bounds of the Institute publications, restricting them very definitely to electrotechnical subjects. Some latitude was allowed, however, in the inclusion of related technical fields. Item (*k*) put the stamp of approval on applications of electricity to social purposes and item (*o*) on ethical and social aspects of the profession.

Suggestions for the Future

Before hazarding any suggestions, some review of the past as presented is in order. It seems that there is a distinct similarity of performance in all the engineering societies. A study of the record will disclose that engineers have shown little inclination to interrelate their activities with the whole of life and to deal with the reactions of their activities upon the community. In some quarters they have been described as mere technicians. Almost the whole record is characterized by engineering remoteness. Engineers have built around themselves a high wall outside of which some of our fraternity are well qualified to venture or over which some of us might well cast an occasional glance.

The effect of the recent depression upon the public at large has brought to the fore a definite criticism of the scholarly isolation policy of the scientist and the applied scientist. It is said: "They have applied themselves too narrowly." The opinion of the layman is that the scientists are responsible for the social and economic consequences of their advancement of the theory and practice of their particular branch of science. In President Roosevelt's October 7, 1936 letter to those in charge of technical education, he mentions "the social responsibility of engineering" and says that engineering must "consider social processes and problems and must co-operate, in designing accommodating mechanisms to absorb the shocks of the impact of science."

Dedication to public service is one of the chief requirements of a profession. This dedication is not unrelated to professional recognition. It is therefore suggested that

the Institute rededicate itself to the public welfare in its broadest implications. The appointment of an AIEE national power policy committee is suggested. It is further suggested that engineers should not labor exclusively within their own hereditary field; that they should not ignore the criticisms of laymen in other fields; and that they should not continue their scientific detachment and remain unconcerned with the human relationships of their activities. The Institute might well appoint a public relations committee to find ways and means to interpret the engineer to the public.

Lastly and specifically it is suggested that the publication policy strive to increase the percentage of papers on social and economic subjects. This is nothing new to our Institute as evidenced by the 1911–17 group of papers and this is in no way inconsistent with the code of the technical program committee as stated in items (*f*), (*k*), and (*o*).

Social Responsibility of the Engineer

By Frank R. Innes

By a vote of practically 10 to 1 a group of some 180 engineers in attendance at a joint meeting of the AIEE Chicago Section, and of the electrical section, Western Society of Engineers in Chicago, March 22, this year, went on record in favor of "vigorous, effective action" by the professional engineering society in national affairs of engineering nature within its particular field. This vote was taken after the presentation and discussion of 2 papers, the first on the general aspect of the responsibility of the engineer in social and economic matters by Mr. P. B. Juhnke, and the second by your present orator on the specific responsibility of the electrical engineer in electrical-engineering matters that now occupy the forefront of national attention.

This meeting was planned to elicit indications of interest or the lack of it from the rank and file of engineers on, first, whether or not social and economic questions should be discussed at engineering meetings and, second, whether or not the professional engineering society should actively concern itself in national affairs within its technical scope. A ballot was taken on the 2 questions. The vote on the first was: "Yes," 186; "Yes, with reservations," 3; and "No," 2. On the second question, that of active participation of the engineering society in national engineering affairs, the vote was: "Yes," 158; "Yes, with reservations," 10; and "No," 17. This vote indicates positively that the engineer is interested in social and economic matters and wants to discuss them. It also indicates, almost as positively, that the engineer wants his professional society to represent him and act for him in national affairs.

Many of us self-appointed spokesmen for our profession have been talking about the social responsibility of the engineer. We have spoken in general and nebulous terms that are in themselves a denial of the engineering method we recommend. We cannot hope to be taken seriously in our assertions of the superiority of the engineering approach for solution of the social and economic problems of today unless and until we actually use that approach in our consideration of these problems and really begin to work on them in engineering fashion.

The engineering approach to any job is to resolve the job into its component parts so that the problems of each part may be handled and solved by minds qualified by training and experience for that particular work. Each kind of engineer works in a definite field. It is in this familiar way that the engineer must go to work on the big job of solving the social and economic problems that confront him.

We are electrical engineers. What is our share in this big problem of the social responsibility of the engineer? Obviously it is that part which involves electrical engineering. And to what aspect of that part should we give our first attention? Obviously again, we should give our first attention to that affair of electrical engineering in which government is now most active and in which the nation is now most interested. We are being asked by voices from outside our technical ranks to take action in this particular matter.

Doctor Raymond Moley in a recent issue of the magazine *Today* puts up to us this question: "All of us who are not engineers have been taught to believe that water power is the cheapest and most efficient and most permanent source of electrical power. Are we right or have we put our faith in a delusion?"

In various forms this question is appearing more and more in the public prints, as, for instance, in a Chicago Tribune editorial "Forty Years Behind," in which the government is charged with not being up-to-date in its power program. I have seen the same subject treated in other newspapers. I recently received a letter from Mr. Wesley Winans Stout, editor of the *Saturday Evening Post*, in which he stated he had editorialized on this subject 10 years ago.

Well, since the engineer as a professional class is being asked by the world outside to do something about this water-power matter, and since it is indicated by the vote in the Chicago meeting that the rank-and-file engineer wants something done, just what can the American Institute of Electrical Engineers do? This also is obvious. The Institute can examine the water-power program of the government and report on it to the nation commending what is found worthy in it and condemning what is unworthy.

Specifically, the Institute should investigate and report on criticisms of the program that are commonly current among engineers. Some of these criticisms are:

1. The only markets for the outputs of some of the government plants are those which can be taken away from existing utilities, the government thus endangering the investments of its citizens. Most of the other government plants are so remote from possible markets that it can be said for them that markets do not exist.

2. Today electricity can be supplied just as, or more, cheaply from fuel power plants close to the load than it can from remote water powers with long transmissions. It costs less to haul coal than to transmit electricity.

3. Water power, from an efficiency standpoint, is practically a completed art. At the same time its competitor, steam power, though less efficient on a thermal basis, has already surpassed it considering over-all plant economy. And the opportunity for further economy in the steam plant is very great.

4. Building water-power plants may aggravate the unemployment problem. It largely reduces plant operating labor and eliminates entirely labor for production and transportation of fuel.

5. Financing periods of half a century, which seem necessary to justify projects in the government program, appear indefensible in this day of rapid technical development.

These are the opinions of many engineers, not mine only. Probably there are some engineers who may see merit in the government program of water-power development, but I think all will agree that some of the criticisms mentioned may be justified in sufficient degree to warrant investigation and report to the people.

To be definite, I suggest that the Institute establish committees or boards of competent engineers to study and report on government projects of an engineering nature or to initiate and assure such studies by American Engineering Council or other co-oper ve agencies. Due to political emphasis on hydroelectric projects at this time it seems logical that this subject should receive first consideration. The findings of these investigations should be given the widest possible publicity.

It is a good thing for us to talk about the social and economic responsibility of the engineer, but it is a better thing for us to *do* something about it. The nontechnical world is asking us to act and the members of our professional organizations are telling us to act. Apparently then, we should act.

Institute Programs

By Mark Eldredge

Programs for many organizations are arranged with the purpose of being interesting, but the subject for discussion puts the emphasis on "value to the membership," and that is the thought in these remarks.

We have 19 technical committees, all producing papers of keen interest to those members whose work lies along the lines of the specific subjects treated. These papers presented on Institute programs are not only interesting but are valuable to many of us because of the things we learn that have application in our individual fields of endeavor. Their value is measured in terms of our jobs which are so absorbing that frequently they are the beginning and end of our existence. Sometimes I think we engineers are like a colony of ants going here, going there, doing this, and doing that. We seldom take time to stand off and view in perspective the whole big job of living and note the part we play. Are we helping to build an ant hill or a path to a higher point? Do we comprehend where this or that new engineering development is taking us? Most of us are so absorbed in the daily routine that we give little thought to the part our own contribution to life adds to the world's real progress, or, if conscious of progress, we seldom consider the trend and whether the direction is right.

It seems to me there is one certain type of papers that would be most valuable to us all. Such would be studies or research on the effects certain details of technical progress have on general progress and improvement of human well-being. Since the first of the year, we have had some excellent general papers, such as, M. E. Leeds' "Engineering and Economics," John C. Parker's "Power and People," Harold G. Moulton's "Engineering Progress and Economic Progress," and R. C. Muir's "Some Engineering Contributions to Society." Between these

and the strictly technical papers lies the field I have in mind—papers that show the wide-reaching effect specific engineering achievements have had on social or national progress. In some cases, a chain or sequence of applications of some modern discovery might be shown to have had a very marked influence on the world. To be more definite, consider what a very romantic story might be told of the development of electron tubes; but, more important, what an amazing story might be unfolded of what they have already done to change and, we hope, to improve civilization. We can surmize some of the effects, but the results of research along this line might make a program of greatest value to the membership. It might awaken in us a greater realization of our ability to benefit the world.

Take another possible subject for a paper or a program: The discovery of a light-sensitive element made possible the light meter, which is doing so much to make people light conscious. What economic reaction is observable? Would not our lives be more purposeful if, while doing our routine tasks, we turned our thoughts more often to a consideration of the influence our particular bit of engineering progress is having on the world about us?

AIEE Tradition and Policy

By J. B. Whitehead

For a number of years there has been increasing comment that engineers should take greater part in the discussion of questions of public interest and in the direction of certain types of public affairs. Such comment has often been heard within the AIEE, and more recently discussion and resolutions have been introduced into meetings of the board of directors proposing the formation of active committees not only for stimulating such discussion, but even proposing that the Institute should expend money and effort for examinations and investigations, and take public position on certain questions, in many instances necessarily, from their nature, of controversial character.

The Institute has so far, throughout its long and successful life been a conservative professional body devoted to the advancement of the electric art. It is the conviction of many of its members that its very life blood from the beginning has been its constant production of high-grade technical and scientific papers. It is certain that most of the young men who come into the Institute, and who ultimately become useful members, are those who are attracted by our strictly professional activity. Constructive and creative members of the Institute are almost invariably from this class. Few people will question that the high and strong position of the Institute throughout its more than 50 years of life, and its present healthy condition are due to its traditional policy of adhering to its fundamental purpose, "the advancement of the theory and practice of electrical engineering."

It becomes of great importance then to examine carefully any proposals for departures from our traditional policy. A review of some of the subjects that have been proposed for examination and discussion by the Institute, as a means of broadening its activities, reveals a startling conception on the part of some of our members of its proper range of discussion and action. One formal proposal that the Institute take a more active part in the examination of questions of the day lists among others the following: the effect of increase or decrease of values upon the workings of the national productive plant; comparison of American and Old World state of prosperity, and causes for the difference; the effect of unearned increment upon the state of American prosperity; the pros and cons of taxation; governmental efforts to regulate farms; better control of industrials; the overexpansion of productive facilities in utilities and railroads and the possibility of their regulation; the effect of regulation which destroys values, etc. Incidentally, it is proposed that the discussion of these questions should be free of political aspects! Another contributor suggests that a quarter of the activities of the Institute be devoted to the discussion of sales and commercial activities. Another wishes to see symposia for the discussion of all types of federal relief programs. Still another wishes to discuss, and presumably that the Institute should make public utterance on, the registration of engineers, the principles underlying public-works projects, the development of of engineers' unions and the depressing effect of federal power policies. Engineering examinations and public reports by the Institute on the Passamaquoddy and Fort Peck projects, and indeed on hydroelectric power in general, are seriously proposed.

In fact, if the complete list of all the proposals that have been made were given, it would be seen that there are few questions of the day, on whatever subject or of whatever character, which are not seriously proposed as proper matter for the expenditure of time, effort, and money by the membership of traditionally conservative AIEE. Here then are proposals from our own members for very radical expansions of our programs and wide departures from our avowed purpose of the advancement of the electric art and profession. We may well pause for a brief word of examination and comment.

No one will question the importance of every one of these problems and the interest in them of every good citizen. Every one of us would certainly wish to be identified with any movement which seemed likely to arrive at proper solutions of, or even to throw important light on, any of these contemporary problems. Especially so in these New Deal days when we so often experience irritation and impatience that so many of our public questions are settled, and public enterprises begun, without the careful study and examination which the engineer likes to see for all new undertakings.

The question, however, is where to begin and how to proceed? In most such problems great uncertainty exists as to essential fundamental facts, and premises based on recognized principles are not evident. Owing to their contemporary character, the causes giving rise to these questions are obscure, differences of opinion pronounced, and the elements of personal and group material and political advantages enter. How can an engineer deal effectively, even to his own satisfaction alone, with questions so involved in obscurity? The answer is that he cannot. Given the time and money, he might, it is true, examine a concrete government undertaking such as the Passamaquoddy power project, and even its economic feasibility; but would that answer the still deeper question of the validity of the government's purposes in undertaking it? Where would AIEE get with an examination of the Tennessee Valley Authority and its activities, when there are differences within its own board of engineers as to its proper development, and when there are questions between TVA and local power companies which have advanced through all legal stages up to the Supreme Court of the United States?

To my mind there are 2 very simple answers to the often repeated questions as to why an engineer does not take a more prominent part in public affairs. The first is that public questions are never sufficiently concrete, nor clearly defined, to permit quantitative determination, or even an enumeration of fundamental factors or elements. Second, even where such questions approach the tangible and concrete, it is by no means certain that legislation or public action will not be based on political expediency or group interest, rather than in accordance with correct economical engineering plan. Engineers are primarily rational and honest, and these virtues are not always at a premium in our present methods of solving contemporary public questions.

As contrasted with these extreme proposals, it is worth while to recall a report on Institute policy made to the board of directors in 1931 by National Secretary F. L. Hutchinson. The subject of the report was the desirability that the Institute's activities be extended in certain directions. The headings in the report indicating these suggestions, were as follows: Legislation Affecting the Engineering Profession; State Councils of Engineers; The Economic State of Engineers; Employment Service; Education of the Public Regarding the Engineering Profession; Engineering Education; Extension of Institute Work Throughout the Membership.

Not much suggestion here of the diverse economic, social, and political questions referred to hereinbefore. Moreover, it is a fact that every one of the subjects mentioned in Secretary Hutchinson's report is now being handled by well-organized committees, either of joint character with other societies as in American Engineering Council and Engineering Societies Employment Service, or within normally constituted committees of the Institute.

Happily, the extreme broadening programs mentioned have not been received with very wide acclaim, and those advocating them have taken a more moderate position recently. On the other hand, greater opportunity within the Institute for the discussion of questions of public interest, particularly where they touch the engineering profession, has been very extensively advocated. We have already taken some steps in that direction. And we are here today to discuss advisability of even further moves. Let us examine briefly the origin and character of this movement.

The Institute is open to anyone interested, no matter how remotely, in the development of the electrical art. As a consequence, we have among our members a very wide range of professional ability, attainment, and duty. It is a fine thing that this should be so. The Institute should nurture particu-

larly its lower grades of membership. It needs their support and it needs recruits from their ranks for the working forces of its manifold activities. With the rapid expansion of our industrialization, this group within the Institute has become increasingly large. As it becomes large, it is natural that it should become more vocal. We should not blind ourselves, however, to the fact that its members are not yet completely nor broadly developed professionally, and that their opinions and proposals are often without sound basis in tradition, knowledge, and experience. For example, from this group come those who occasionally raise the question of what they get in return for their dues, mentioning only Electrical Engineering and the fact that they cannot understand much that it contains. It is a question whether members who persist in this attitude and do not develop in some phase of the Institute's work ever attain full realization of the Institute's high purposes.

It is a day of aggressive democratization and socialization. The great levelling processes that are being urged everywhere, and we are now discussing an example, invariably suppress independent thinking, the application of new knowledge, and the advance of civilization. Witness the widespread suppression of research and initiative in Europe. It begins to look as though the English-speaking races are the only ones in which intellectual liberty can be expected to continue to blossom in the results of scientific effort and experimental research. We must, therefore, look out especially for these dangers not only in our country, but also within the Institute.

Unfortunately such dangers do not always seem to be appreciated even among our older members. Not long ago I heard one of them voice the belief that, being a membership organization, it was the duty of the Institute, and so that of its board of directors, to ascertain the wishes of the greatest number of its members, and to legislate accordingly. This, to my mind, is doubtful doctrine. When it comes to duty, the onus should be on the opposite side, namely, it should be the duty of every member of the Institute to consider that which will best contribute to the maintenance and elevation of its high standing, not only of professional conduct, but of professional achievement. The Institute from its beginning has been primarily a technical, professional, and scientific society. Its usefulness, dignity, and authority will be steadily impaired by just so much as we depart from the pursuit of these high purposes.

We should therefore go slowly with our programs of expansion into general fields. Material for publication, from outside our own ranks, is correspondingly difficult to scrutinize. Our columns have on occasion even been opened, though fortunately not often, to nonmembers with pet theories to advertise or other axes to grind. Committees with a specific broadening purpose to my mind are of doubtful value. Committees do not write or create papers. They look for papers rather than at the quality of material in them. Good papers are produced by individuals, each with a message which must find utterance. Moreover, we already give substantial support to general discussion in that through the publication and education committeees we are devoting to it an increasingly large amount of space in Electrical Engineering. Much of the material so presented is good, and it seems to me that in these and other available channels, we already have ample facilities for the publication and discussion of general questions of all types.

Let it be remembered also that those public questions which would appear to be better solved by engineers, usually involve engineers of all types, not merely those in the electrical field. Also that a number of agencies such as the American Engineering Council, the Engineers' Council for Professional Development, the United Engineering Trustees, Engineering Foundation, and others, have been set up especially to deliberate and serve us as channels of communication with all forms of public activities involving the interests of the engineering profession and the possibilities of its utilization. Certainly so far as formal expression of approval from the engineering profession on any great public question is concerned, examination and study by one or more of these bodies, and final utterance through them, would have far greater value and authority than if undertaken within a single constituent member society.

What then must be said in reply to the question constituting the subject of this meeting? My answer is somewhat as follows:

Many social, economic, political, and other public questions frequently touch the interests, either material or other, of electrical engineers. Intelligent discussion of such questions by electrical engineers, therefore, becomes both proper and desirable. The Institute already offers high favorable opportunities for such discussion through the columns of Electrical Engineering, and in the meetings of Sections' representatives at conventions and in meetings in the Sections themselves. I know of no reason why a thoughtful, well-considered paper on any such subject should not be accepted for publication in Electrical Engineering. It is my belief also that there should be no restriction upon the range of topics discussed at the meetings of Sections' delegates, or in the Sections themselves.

The essential principles to be adhered to in connection with these activities are: first, that the Institute, its Sections, and any gathering of Institute members, must avoid formal endorsement and opinion in the name of the Institute, on public questions of controversial character. Papers and reports should be distinctly under the names of their authors, and submitted for publication through the regular Institute channels. The second principle is that formal papers for publication should be only of the highest grade, always carrying the weight of authority. The grounds upon which these principles are advocated are that questions controversial in character cannot be settled in terms of known facts and knowledge, and lead frequently to differences of opinion, which in their turn, often lead to antagonism as between groups. Such a condition obviously leads to a disturbance of unanimity and that pursuit of common interest which has characterized all work of the Institute in the past.

In my opinion the programs of our meetings are already extremely good. I have little suggestion for their improvement. By all means let us have increasing opportunity for discussion of general subjects in sessions such as the present one. But as regards publication, let there be constant careful scrutiny of papers of both technical and especially those of nontechnical character, so that the quality of both types may be steadily improved, even if the quantity of published matter be thereby reduced.

AIEE Directors Meet During Summer Convention

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at the Hotel Schroeder, Milwaukee, Wis., on June 24, 1937, during the annual summer convention of the Institute.

Present: *President*—A. M. MacCutcheon, Cleveland, Ohio. *Past-Presidents*—H. P. Charlesworth, New York, N. Y.; J. B. Whitehead, Baltimore, Md. *Vice-Presidents*—O. B. Blackwell, New York, N. Y.; L. T. Blaisdell, Dallas, Tex.; Mark Eldredge, Memphis, Tenn.; R. H. Fair, Omaha, Neb.; C. Francis Harding, Lafayette, Ind.; W. H. Harrison, New York, N. Y.; C. E. Rogers, Seattle, Wash.; A. C. Stevens, Schenectady, N. Y. *Directors*—F. M. Farmer, New York, N. Y.; F. Ellis Johnson, Columbia, Mo.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; K. B. McEachron, Pittsfield, Mass.; L. W. W. Morrow, Corning, N. Y.; C. A. Powel, East Pittsburgh, Pa.; R. W. Sorensen, Pasadena, Calif. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. Present by invitation: *Past-Presidents*—D. C. Jackson, Cambridge, Mass.; P. M. Lincoln, Ithaca, N. Y.; Charles F. Scott, New Haven, Conn. *Officers-Elect*—C. R. Beardsley, Brooklyn, N. Y.; V. Bush, Cambridge, Mass.; F. H. Lane, Chicago, Ill.; M. J. McHenry, Toronto, Ont.; I. Melville Stein, Philadelphia, Pa.; Edwin D. Wood, Louisville, Ky.

Minutes of the meeting of the board of directors held May 24, 1937, were approved.

A report was presented and approved of recommendations adopted by the board of examiners at its meeting on June 16, 1937. Upon recommendation of the board of examiners, the following actions were taken: 4 applicants were transferred to the grade of Fellow; 13 applicants were transferred and 25 were elected to the grade of Member; 116 applicants were elected to the grade of Associate; 88 Students were enrolled.

Disbursements in June amounting to $22,774.41 were reported by the finance committee and approved.

Authorization was given for the organization of a Tulsa (Okla.) Section of the Institute and of a Wichita (Kans.) Section.

Upon request of the committee on safety codes and recommendation of the Institute policy committee, the board authorized a change in name of the former committee to "committee on safety," a change in its activities to the consideration and investigation of matters relating to the protection of persons and property against hazard due to or resultant upon the presence of electricity or the use of electrical apparatus,

material, and appliances, and the inclusion of its chairman among the ex-officio members of the technical program committee. The matter of changing sections 81 and 68 of the by-laws accordingly was referred to the committee on constitution and by-laws.

A special committee on Institute activities had been appointed to arrange for a session at the summer convention for the discussion of the subject of desirable topics for presentation at Institute meetings and for publication in ELECTRICAL ENGINEERING, and to report to the board of directors its reaction to such discussion. The session was held on June 23, and the committee's report thereon was presented. Action was deferred, copies of the report to be sent to the members of the board for study before final consideration.

Upon request, Past-President Charles F. Scott, an Institute representative upon the Engineers' Council for Professional Development, also chairman of that organization, presented a report concerning certain recommendations of the committee on professional recognition of ECPD, which had been submitted to the board of directors for consideration and action. As a result, the board authorized the appointment of a committee of 3 members of the board to study the recommendations and report to the board of directors. The following members of the board of directors for the administrative year beginning August 1, 1937, were appointed members of this special committee: W. I. Slichter (*chairman*), C. R. Beardsley, and O. B. Blackwell.

The board voted to extend an invitation to the members of the International Conference on High Voltage Systems (CIGRE) who may be visiting the United States at the time to attend the AIEE summer convention to be held in Washington, D. C., in June 1938.

In connection with the 1937 summer convention held at the Hotel Schroeder, Milwaukee, Wis., June 21–25, 1937, the board adopted resolutions of appreciation of the effective services of the general convention committee and the various subcommittees, and of the ladies committee, and also expressed its appreciation of the courtesies and assistance extended by the Hotel Schroeder, convention bureau of the Milwaukee Association of Commerce, Allis-Chalmers Manufacturing Company, Harnischfeger Corporation, The Milwaukee Electric Railway & Light Company, Cutler-Hammer, Inc., and Wisconsin Telephone Company.

Authorization was given for the usual allowance for traveling expenses of regular delegates from Pacific District (No. 8) and the University of British Columbia Branch to a joint conference on student activities to be held in Spokane, Wash., during the 1937 Pacific Coast convention, including also the member of the national committee on Student Branches in Pacific District (No. 8). In view of the fact that special action on such joint conference is taken each year, it was voted that a special committee be appointed to study the matter and recommend a permanent policy for inclusion in the by-laws, the committee to consist of the vice-presidents of the 3 Districts concerned, the chairman of the committee on Student Branches, and the chairman of the Sections committee as chairman.

There was an expression of the appreciation of the members of the board of directors of the very faithful devotion of President MacCutcheon to the duties of his office and the large amount of time contributed by him in furthering the best interests of the Institute.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

New Name and Scope for Safety Codes Committee

The name of the AIEE committee on safety codes has been changed to "committee on safety," and its activities changed to: the consideration and investigation of matters relating to the protection of persons and property against hazard due to or resultant upon the presence of electricity or the use of electrical apparatus, material, and appliances. Its chairman now is to be included among the ex-officio members of the technical program committee. These changes were authorized by the AIEE board of directors at its meeting of June 24, 1937, upon request of the committee on safety codes and recommendation of the committee on Institute policy.

One of the general committees of the Institute, the committee on safety codes was established in 1902, and has functioned continuously since that time. Previously, the scope of the committee, as defined in section 81 of the Institute's by-laws, was to consider and investigate all matters relating to the formulation of rules for the protection of persons and property against fire, accidents, and other hazards in connection with electrical installations and equipments, and to confer with similar committees of other bodies regarding the same.

Canadian Engineers Celebrate Semicentennial

The Engineering Institute of Canada, founded in 1887 as the Canadian Society of Civil Engineers, celebrated its semicentennial during a series of meetings held in Montreal and Ottawa, June 14–19, 1937. Although the society originally was chartered as a civil-engineering society, by 1918 a much broader scope seemed to be desirable and the name of the organization was changed to Engineering Institute of Canada. Today the organization claims members within almost every class of engineering, and these various interests were reflected in the sessions of the anniversary meetings.

The opening session of the celebration was devoted to greetings from other societies and to the conferring of honorary degrees and awards. President A. M. MacCutcheon was the official AIEE representative at this session. The technical program included 5 sessions at which 22 papers were presented. By way of diversion inspection trips were made to engineering works in the Montreal and Ottawa districts.

Lamme Medals Awarded by SPEE and Ohio State

In addition to the Lamme medal awarded annually by the AIEE, other Lamme medals are awarded by the Society for the Promotion of Engineering Education and by The Ohio State University, Columbus. These medals are made possible by 3 bequests provided in the will of Benjamin Garver Lamme (deceased July 8, 1924). As reported elsewhere in this issue, the AIEE Lamme medal for 1936 was presented to Doctor Frank Conrad (A'02) during the Institute's recent summer convention at Milwaukee, Wis.

The SPEE awarded its tenth Lamme medal July 1, during its convention at Massachusetts Institute of Technology, Cambridge, to Dean Frederick E. Turneaure of the college of engineering of the University of Wisconsin, Madison, "for his influence upon the policies and people of the college of engineering of the University of Wisconsin; for his conception of a university as a co-operative enterprise of scholars and disciples in which freedom and power to initiate is diffused, not centralized; for the spirit of steadiness and confidence he has engendered; for the harmonious and co-operative relations within faculty and between faculty and students that have matured under his leadership; and in recognition of the high place he has filled in engineering education and in public estimation not only in his commonwealth but in the nation as well." Dean Turneaure was born on a farm near Freeport, Ill., July 30, 1866; graduated in civil engineering from Cornell University, Ithaca, N. Y., in 1889, and immediately engaged in railway engineering work; became an instructor in civil engineering at Washington University, St. Louis, Mo., in 1890; has been affiliated with the University of Wisconsin since 1892, since 1904 as dean of engineering. He is a past-president of the Society for the Promotion of Engineering Education (1908–09) and was a member of the board of investigation and co-ordination which directed the comprehensive study of engineering education carried out by that society from 1923 to 1929.

Two Lamme medals were awarded this year by The Ohio State University. One medal went to E. C. Bain, metallurgist and assistant to the vice-president of the United States Steel Corporation, New York, N. Y.; the other to Ellis Lovejoy, consulting engineer in ceramics, Columbus, Ohio. These medals were presented at the 1937 commencement exercises of the university, and, in accordance with the stipulations governing the awards, both are Ohio State graduates. Doctor Bain received the degree of bachelor of science in chemical engineering in 1912, master of science in 1916, and chemical engineer in 1923 from Ohio State. He received the honorary degree of doctor of engineering from Lehigh University, Bethlehem, Pa., in 1936. He has been engaged in metallurgical research for 15 years and is said to be the youngest engineer to receive the Ohio State Lamme medal. He was awarded the Robert W. Hunt medal of the American Institute of Mining and Metallurgical Engineers in 1929, and was Howe Memorial Lecturer of that society in 1932. Doctor Bain has

made important contributions to literature dealing with application of X rays in metallurgical research, the heat treatment of metals, and particularly the development of stainless and heat-resisting steels. He is president of the American Society for Metals. Mr. Lovejoy was graduated in mining engineering from Ohio State in 1885, 10 years before the department of ceramic engineering was established. He has spent more than 50 years in engineering research, invention, and management with the ceramic industry, and has been a consulting engineer in ceramics since 1904. He is the inventor of several original ceramic products, and the author of a number of papers, discussions, brochures, and books on various phases of the ceramic industry. He is a past-president of the American Ceramic Society.

Middle Eastern District to Meet in Akron, Oct. 13–15

A 3-day meeting of the AIEE Middle Eastern District will be held in Akron, Ohio, October 13–15, 1937. Tentative arrangements indicate that an interesting program will be developed. Akron is a large industrial center and cognizance of such subjects as electrical applications in the rubber industry, lighting, and radio tower insulators, as well as the possibility of electrical applications for the production of iron and steel, will not be overlooked.

In addition to the technical sessions, arrangements will be made for entertainment events and inspection trips to places of interest in the vicinity. Other details will be announced when available.

Members of the Middle Eastern District meeting committee who are making the arrangements are as follows: Harold L. Brouse, *chairman*, I. Melville Stein, H. A. Dambly, A. G. Ennis, Paul Frederick, W. H. Harrison, W. C. Kalb, E. E. Kimberly, E. O. Lange, and O. C. Schlemmer; the following are chairmen of the committees indicated: A. O. Austin, meetings and papers; R. A. Hudson, entertainment and reception; H. H. Schroeder, attendance and publicity; H. C. Paiste, transportation and inspection; V. W. Shear, hotels and registration; J. T. Walther, student activities; Ralph Higgins, finance.

Lamme Medal Nominations Due November 1

Attention is called again to the opportunity open to any member of the Institute to submit nominations for the 1937 Lamme Medal. All nominations must be received not later than November 1. (For further particulars, see ELECTRICAL ENGINEERING for June 1937, page 756.) The 1936 Lamme Medal was presented to Doctor Frank Conrad, assistant chief engineer of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., at the opening session of the recent AIEE summer convention in Milwaukee, Wis.

ECPD Publishes Engineering Bibliography

The committee on professional training of the Engineers' Council for Professional Development has just published 5 pamphlets which, taken together, should prove helpful to those in search of competent guidance in engineering literature. Primarily intended to aid the beginning engineer in choosing his reading, the lists should also be of service to librarians as guides in book purchasing.

The bibliography appears in 5 sections: (1) mathematics, mechanics, and physics; (2) aeronautical and civil engineering; (3) chemical and industrial engineering; (4) electrical and mechanical engineering; (5) metallurgical and mining engineering. These lists represent the considered opinion of many teachers and professional engineers. The choice of works has been confined to current American publications and, in general, to those of college grade. Annotations are provided.

The separate pamphlets can be had for 10 cents each, or for 5 cents each in lots of 50 copies, assorted if desired. Requests should be sent to Engineer's Council for Professional Development, 29 West 39th Street, New York, N. Y.

McGraw-Hill Presidency Changes

The presidency of the McGraw-Hill Publishing Company, Inc., of New York was transferred as of June 21, 1937 to James H. McGraw, Jr., as the result of the resignation of Malcolm Muir from that post.

A Princeton graduate (1915) Mr. McGraw has served his company actively in various capacities; he became treasurer in 1923, executive vice-president in 1932, and in 1935 was elected chairman of the board to succeed James H. McGraw (A '01) founder of the company. In addition to his duties as president, he will continue as chairman of the board, according to the company's announcement

Malcolm Muir resigned the presidency of the McGraw-Hill company to assume the presidency of the company publishing *News Week*. He had served the McGraw-Hill company continuously since 1905 in various capacities including the general management of *Chemical and Metallurgical Engineering*, and later of that publication together with *Coal Age* and *Engineering and Mining Journal*. He became vice-president of the company in 1916, and president in 1928.

ASTM Elects Officers. At the first session on June 28, 1937, of the annual meeting of the American Society for Testing Materials, election of the following officers for 1937–38 was announced: *president*—A. E. White, professor of metallurgical engineering, and director, department of engineering research, University of Michigan, Ann Arbor; *vice-president*—H. H. Morgan, manager, rail and track fastenings department, Robert W. Hunt Company, Chicago, Ill.; *members of executive committee*—P. H. Bates, chief, clay and silicate products division, National Bureau of Standards, Washington, D. C., H. F. Clemmer, engineer of material, District of Columbia, Washington, G. E. F. Lundell, assistant chief, chemistry division, National Bureau of Standards, Washington, D. C., H. G. Mougey, chief chemist and assistant technical director, research laboratories division, General Motors Corporation, Detroit, Mich., and R. L. Templin, chief engineer of tests, Aluminum Company of America, New Kensington, Pa.

Secretary of Institution of Civil Engineers Dead

Doctor Henry Homan Jeffcott, since 1922 secretary of The Institution of Civil Engineers, died June 29, 1937. He received his education at Trinity College and Dublin University and held the degrees of bachelor of arts, bachelor of engineering, and doctor of science. At Trinity College he was "first mathematical scholar, senior moderator and gold medalist, and M'Cullagh prizeman." Doctor Jeffcott's early engineering endeavors included brief associations with Siemens Brothers and Company, Ltd., Woolwich, England, as assistant engineer, and with Whitworth and Company, Ltd., Manchester. From 1905 until 1910 he was head of the metrology department of the British National Physical Laboratory.

In 1910 Doctor Jeffcott was appointed to the faculty of the Royal College of Science for Ireland, with the rank of professor of engineering, and remained at that institution for 12 years before being appointed to the secretaryship of The Institution of Civil Engineers. During the last 8 years of his stay at the Royal College he was dean of the college faculty. From 1918 to 1921 he was secretary of the subcommittee on water-power resources of Ireland, and since 1922 had been a member of the board of studies in civil and mechanical engineering of the University of London. Formerly, he was an examiner in mechanical engineering in the University of Belfast, and in the National University of Ireland. He held several patents on mechanical devices, and was the author of numerous technical papers.

AIME Announces Meetings. Dates and places for 1937 fall meetings of the American Institute of Mining and Metallurgical Engineers have been announced as follows: September 13–18, regional meeting (joint meeting with the Canadian Institute of Mining and Metallurgy), Vancouver, B. C.; September 30–October 1 (tentative) petroleum division, Los Angeles, Calif.; October 7–8, petroleum division, Oklahoma City, Okla.; October 14–16, industrial and minerals division, Washington, D. C., and College Park, Md.; October 18–22, Institute of Metals and iron and steel divisions, Atlantic City, N. J.; and October 27–28, coal division, Pittsburgh, Pa.

H. L. Cooper, Hydroelectric Consultant, Dies

Hugh Lincoln Cooper, president of Hugh L. Cooper and Company, Inc., New York, N. Y., and a world-renowned builder of hydroelectric power plants, died June 24, 1937, at his home in Stamford, Conn., after a brief illness. Colonel Cooper was born April 28, 1865, at Sheldon, Minn. Although he never received a formal engineering education, he received the honorary degree of doctor of laws from the University of Missouri and Parsons College, an honorary degree of doctor of engineering from Syracuse University, and an appointment as honorary professor of civil engineering at the State School of Engineering of the Republic of Brazil. He began his engineering career in 1881, as an apprentice engineer for the Chicago, Milwaukee, and St. Paul Railway Company, but after 3 years joined the engineering staff of the Chicago Bridge and Iron Company, and in that company he first established a reputation for himself as a structural designer.

In 1891 he went to Spokane, Wash., as northwestern manager of the San Francisco Bridge Company, where for 3 years he designed and built bridges, including a 500-foot steel arch for the Spokane Falls and Northern Railroad Company; however, he believed that hydroelectric development extended a great opportunity for engineering achievement, and in 1894 he began bidding independently on small water-power construction projects in the state of Washington. In 1897 he sought and gained a position as assistant chief engineer for the Stillwell-Bierce and Smith-Vaile Company, manufacturers of water wheels, of Dayton, Ohio, so that he might learn the fundamentals of turbine design.

Colonel Cooper's first big hydroelectric project was a 20,000-horsepower plant in the mountains of Brazil, for the Sao Paulo Tramway, Light and Power Company. From there he went to the Mexican Power and Light Company as chief engineer, and then to the Electrical Development Company of Ontario as chief hydraulic engineer. In 1901 he established his own consulting engineering practice, and for the next 12 years supervised the construction of many hydroelectric plants, including the 165,000-horsepower Keokuk development on the Mississippi River. During the World War he served as a Colonel in the Corps of Engineers of the United States Army, but was recalled from France to supervise the construction of the Muscle Shoals dam and power house on the Tennessee River. His most recent engineering achievement was the supervision of the construction of a 750,000-horsepower plant for the Union of Socialistic Soviet Republics, the Dnieprostroy Dam. He was a member of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, Society of American Military Engineers, American Institute of Consulting Engineers, Institution of Civil Engineers (Great Britain), and the Institution of Water Engineers (Great Britain).

Current Items From American Engineering Council

Proposed Increase in Engineering-Experiment Stations

Council is being called upon by members of Congress, engineers, and educators in the land-grant-college groups to support legislation proposing to increase the number of engineering-experiment stations and for advice regarding the attitude that should be taken toward such legislation. It has also come to Council's attention that there is competition between the "A and M" colleges and state universities for the allocation of funds for the construction and operation of engineering-experiment stations.

So much confusion has arisen regarding this legislation that President Roosevelt has appointed 3 committees to study it. The National Research Council was first called upon to appoint a committee headed by Doctor Charles W. White. After that committee had gotten into action, some question arose as to whether it should make a final report, and the President appointed a committee on industrial training headed by Doctor Floyd Reeves of Chicago, Ill., who was formerly director of personnel with the Tennessee Valley Authority. A third committee has just been started by the National Resources Committee to investigate human resources, which is understood to include questions regarding engineering educational facilities in land-grant colleges.

In addition to this legislation, it is interesting to note that money is now being appropriated from relief funds to colleges for research and other purposes through 3 different organizations: under relief projects set up under the Works Progress Administration; under the National Youth Administration, which operates under a committee of which Mr. Joseph Roach is chairman and Mr. Audrey William is director, with substations in each state dealing with appropriating funds to the colleges and universites in each state; and a program of expenditure under Doctor Frank Persons of the Department of Labor for special purposes.

Such appropriations add to the confusion of purpose in current legislation and indicate that engineers should make a careful study of the entire situation before approving any of the proposed legislation or procedure. It is probable that some more acceptable form of federal support for engineering-experiment stations may result from the studies now being made by the president's committees and it may be advisable to wait for their recommendations.

Council's natural position in this matter is to represent the engineering viewpoint and the engineering profession of the country in the public welfare, and the staff is reluctant to go into controversy beyond that point in support of any legislation. Therefore, Council is endeavoring to confine its work in this connection to the accumulation and dissemination of information concerning the several pieces of legislation, including the opinions of member engineering organizations and Council's own committees.

Copies of the proposed bills have been mailed by Council to various interested parties. The AEC staff is contacting the chairmen of the President's committees and will advise its member organizations of additional information on this important issue as such information becomes available.

Statistical Yearbook of World Power Conference

One of the objectives of the World Power Conference is the preparation of inventories of the resources of the world in fuel and power. The first inventory entitled "Statistical Yearbook of the World Power Conference," now ready for distribution, represents an excellent attempt to compile and publish international statistics of power resources, development, and utilization upon a comprehensive and comparable basis. Some of the information has not been published before in any country. As a collection of statistics on this particular subject, the work is probably unique and for this reason may prove most valuable to those interested in the development of world power resources.

Engineers, economists, statisticians, and others who require such information as comparable figures of coal consumed in the USA and the USSR, or of electricity generated in metallurgical works in Poland and Japan, or estimates of the world production of petroleum or wood, or the proportion of electricity generated by water power will find much of the information which was available in 1933 and 1934 in this compact volume which is being sold at $5 per copy by the American National Committee, World Power Conference, Interior Building, Washington, D. C.

March of Rural Electrification

Rural electrification has increased from virtual stagnation during the depression to the highest peak in history. Without taking into consideration the new distribution lines constructed with federal financing, more new customers were connected to farm power lines in 1936 than in any other year since "electricity started to the country." Plans for 1937 indicate that privately financed lines will exceed those of 1936 and that the use of electric energy in rural areas is "on its way."

A large part of the increase in the rural use of electricity is said to be due to the

abandonment by utility companies of the practice of requiring farmers and rural industry to contribute to the cost of the lines which serve them. In many areas, distribution lines are being constructed to the consumers' property line without cash or deferred payment for such lines. Another contributing factor to the expansion is reported to be found in reductions in the cost of rural lines.

The Rural Electrification Administration reports that REA lines now equal privately financed lines. Plans and specifications prepared by engineers in private practice and approved by the engineering staff of REA are required on all projects, and Council is frequently called upon to suggest candidates for engineering positions in Washington and in the states. The compensation either by fee or salary is not always in keeping with that paid by private industry, but the engineering profession is being permitted to make its contribution to public as well as private rural electrification, and the appreciation of the value of engineering knowledge and experience is increasing and spreading to the less populated areas.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Mechanic Impedance In MKS Units

To the Editor:

The Giorgi, meter-kilogram-second (mks) system of units was adopted by the International Electrotechnical Commission (IEC) at Brussels in 1935.[1,2] The advantages of the mks system are notable and have been fully discussed in various papers.[3–5]

The purpose of this paper is to present the algebraic analogies of electric and mechanic impedance in a system of units that emphasizes the homogeneity of the 2 concepts. Such a system is the practical mks system of Giorgi.

Ohm's law governing continuous electric current flow in an electric circuit was published 110 years ago. In its well-known form it is:

$$I = E/R \text{ amperes} \tag{1}$$

where E is the impressed electromotive force, in volts, and R is the electric resistance in *ohms*. This equation is in the mks system.

Mechanics of Freely Falling Bodies

We may write, in analogy with Ohm's law, the velocity, v, of a freely falling mass:

$$\text{v} = \text{F/R} \text{ meters per second} \tag{2}$$

where F is the gravitational force exerted on the falling mass in *joules per meter* or *newtons** and R is the mechanic resistance to motion of the mass. (The retarding influence of the air is neglected.) The gravitational force exerted on a mass M kilograms is gM newtons where g is the earth's gravitational acceleration at the position occupied by the mass. In mks units g is approximately 9.8 *meters per (second)*.[2] The mechanic resistance, R, may be written as M/t, M being the mass in kilograms and t the time of free fall, in *seconds*. Substituting these values in equation 2, we have the well-known equation:

$$\text{v} = \text{gt} \text{ meters per second} \tag{3}$$

The mechanic resistance of the mass is thus expressed in *kilograms per second* and increases inversely as the time of free fall.

Mechanic Impedance to Alternating Impressed Forces

When the mechanic force, F, impressed upon the mass, M, is not a uniform force of the gravitational type, but a simple sinusoidal alternating or vibrational force:

$$\text{F} = \text{F}_m \sin \omega t \text{ newtons} \tag{4}$$

This vibromotive force tends to set up an alternating or vibrational velocity in the mass, according to the expression:

$$\text{v} = \frac{\text{F}_m \sin \omega t}{\text{Z}} \text{ meters per second} \tag{5}$$

Here Z is the mechanic impedance of the mass to vibrational motion. If the frequency of the impressed vibrational force is steadily maintained at n *cycles per second*, the angular velocity of alternation is, according to a-c electric theory:

$$\omega = 2\pi n = 2\pi/\text{T} \text{ radians per second} \tag{6}$$

T being the period of vibration in *seconds*. Equation 5 is similar to the well-known a-c equation.

$$i = \frac{\text{E}_m \sin \omega t}{Z} \text{ amperes} \tag{7}$$

where i is the instantaneous alternating current in a circuit having a steadily impressed alternating voltage E_m sine ωt and Z is the electric impedance of the circuit in *ohms*. It is known that there is a complete algebraic analogy between the mechanic impedance, Z, and the electric impedance, Z.

$$\text{Z} = R + jX = R + j(L\omega - S/\omega) \text{ ohms} \tag{8}$$

If the electric circuit contains a resistance, R, *ohms*, a simple inductance, L, *henrys*, and a capacitance, C, *farads*, the electric impedance is a plane vector or complex quantity, Z, *ohms* with a real component, R, and an imaginary component, $j(L\omega - S/\omega)$ *ohms* where $S = 1/C$, an elastance in *farads*, and $j = \sqrt{-1}$. That is, the reactance X is the difference between the inductive reactance, $jL\omega$, and the elastive reactance, jS/ω.

If in equation 7 we replace the expression E_m sine ωt by E, effective, or root-mean-square *volts*, it takes the well-known form:

$$\text{I} = \text{E/Z} \text{ effective amperes} \angle^{**} \tag{9}$$

the familiar form of Ohm's law in simple a-c circuits.[6]

Returning to equation 5, the mechanic impedance, Z, takes the form:

$$\text{Z} = \text{R} + j(\text{M}\omega - \text{S}/\omega) \text{ kilograms per second } \angle \tag{10}$$

Here R is the mechanic resistance offered by the medium surrounding the mass to vibrational motion, M is the mass of the body in *kilograms* and S is the elastic force of displacement in *newtons per meter*. It is here assumed that the mass is subjected to elastic restraint directly proportional to the displacement of the mass from its equilibrium position.

In equation 5 if we substitute the effective or root-mean-square value, F, of the impressed vibromotive force for F_m sine ωt, the effective value of the vibratory velocity steadily produced in the mass will be:

$$\text{V} = \text{F/Z} \text{ meters per second } \angle \tag{11}$$

which becomes mechanic Ohm's law for vibrational velocity in the steady state. Mechanic equation 11 is the counterpart of electric equation 9 when the mechanic impedance, Z, is expressed in *kilograms per* second or *mechanic ohms*.

The j operator appearing in equations 8 and 10 may be attributed to the geometric dimensional property of any small circular angle, $d\beta = ds/r$ where ds is the small increment of arc perpendicular to the instantaneous radius vector r; so that, in the plane of reference, $ds = j\, r\, d\,\beta$. Hence, any angular velocity contains, inherently, the dimensions of a perpendicularity.

It may here be noted that the impedances dealt with in the field of acoustics are essentially mechanic impedances and may be expressed in the mks system in *kilograms per second* or *mechanic ohms*.

References

1. IEC Adopts MKS System of Units, A. E. Kennelly. Electrical Engineering (AIEE

* The mks unit of force is known to be the *joule per meter* or that force which, exerted steadily over a distance of one *meter*, does work equal to one *joule*. This name is, however, relatively long and cumbersome. It has been suggested by several writers that this unit of force be provisionally called the *newton* until such time as action by the IEC may assign an international name. 1 newton = 10^5 dynes.

**The angle sign ∠ indicates, as is well known, that the unit is not a simple but a complex quantity, or a plane vector. It may be read *"complex amperes"* or *"vector amperes."*

Transactions), volume 54, December 1935, pages 1373–84.

2. IEC Document R. M. 118, minutes of the International Electrotechnical Commission, meeting of the committee on electric and magnetic magnitudes and units (EMMU), Scheveningen-Brussels, June 1935.

3. Proposals Concerning Electrical and Physical Units, G. Giorgi. International Electric Congress, St. Louis, *Proceedings*, volume 1, 1904, pages 136–41.

4. On the Systems of Electric Units, M. Ascoli. International Electric Congress, St. Louis, *Proceedings*, volume 1, 1904, pages 132–3.

5. A System of "Definitive Units" Proposed for Universal Use, G. A. Campbell. International Mathematical Congress, Toronto, *Proceedings*, 1924; also *Science*, volume 61, April 3, 1925, pages 353–7.

6. Impedance, A. E. Kennelly. AIEE Transactions, volume 10, April 1893, pages 175–216.

Very truly yours,

A. E. Kennelly
(A'88, F'13, HM'33, Life Member, Past-President)

Jackson H. Cook (Enrolled Student)
Harvard University,
Cambridge Mass.

Analogy of Magnetic Circuit and Long Transmission Line

To the Editor:

The solution of magnetic problems has been greatly simplified by the use of the circuit analogy. In such problems, it is generally assumed that the iron constituting the magnetic path carries all the magnetic flux and that the flux "flows" as a result of an applied magnetomotive force. With the exception of the air gap to which the flux is directed, it is generally assumed that the medium surrounding the magnetic circuit is a perfect magnetic insulator. If such an assumption is not made, the usual

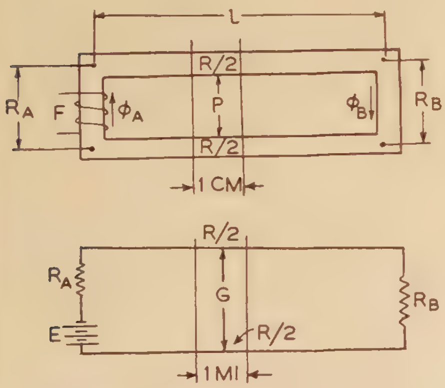


Figure 1. Magnetic "long line"

method is to apply arbitrary corrections to take into account the leakage flux and fringing effects.

It is at this point that the circuit analogy becomes faulty, since electric circuits are generally insulated by media which may be considered perfect. The only type of electric circuit which takes leakage currents strictly into account is the long transmission line, the characteristics of which have been worked out in detail and are readily available. The magnetic analogy of the long transmission line is one in which appreciable transverse leakage exists. It must be assumed that all the leakage flux is of a transverse nature and that the longitudinal leakage is negligible. A sketch of such a circuit is shown in figure 1.

If the constants of the material making up the circuit are known, then the following units are defined:

Magnetic

ϕ—Flux
$\mathcal{F}$—Magnetomotive force
$\mathcal{R}_1$—Reluctance per loop centimeter
$\mathcal{P}_1$—Leakage permeance per loop centimeter
α—Magnetic hyperbolic angle per loop centimeter
$\mathcal{R}_0$—Characteristic reluctance

Electric

I—Current
E—Electromotive force
R_1—Resistance per loop mile
G_1—Leakage conductance per loop mile
α—Electric hyperbolic angle per loop mile
R_0—Characteristic impedance

where $\alpha = \sqrt{\mathcal{R}_1\mathcal{P}_1}$, $\theta = \alpha l$, and $\mathcal{R}_0 = \sqrt{\mathcal{R}_1/\mathcal{P}_1}$.

If the analogous units are used, the relations developed for the electric long line

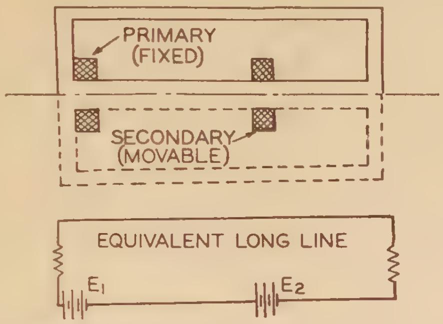


Figure 2. Constant-current-transformer magnetic circuit

can be used directly for the long magnetic circuit. Some useful formulas follow (refer to figure 1):

$$\phi_B = \mathcal{F}_A \times \frac{1}{(\mathcal{R}_B+\mathcal{R}_A)\cosh\theta + \left(\mathcal{R}_0 + \frac{\mathcal{R}_B\mathcal{R}_A}{\mathcal{R}_0}\right)\sinh\theta} \qquad (1)$$

$$\phi_A = \phi_B\left(\cosh\theta + \frac{\mathcal{R}_B}{\mathcal{R}_0}\sinh\theta\right) \qquad (2)$$

$$\text{Leakage flux} = \phi_A - \phi_B \qquad (3)$$

The particular problem to which this method of analysis may be applied is the constant-current transformer, which depends for its characteristics on the leakage flux produced by a magnetic circuit which is of the type described. The magnetic circuit of this transformer, along with its electrical analogy, is shown in figure 2.

The characteristics of a 5-kva 220-volt constant-current transformer, including the leakage inductance, necessary size of counterweights, shape of the sectored disk necessary to maintain optimum regulation, and other pertinent data were computed with ease from the physical constants of the magnetic circuit by the use of long-line formulas adapted to this particular magnetic problem. Tests made on the transformer showed a close agreement between the calculated and measured results.

This is, in general, an effective method of attacking the problem of the leaky magnetic circuit, providing, of course, that it satisfies the long-line conditions imposed on it.

Very truly yours,

J. R. Ragazzini (A'33)
Tutor, The College of the City of New York, New York, N. Y.

Copper and Aluminum Cable Fusing Time-Current Formulas

To the Editor:

In the "Letters to the Editor" of the October 1935 issue of Electrical Engineering, pages 1127–8, there is a letter by H. J. Reeves (A'30) regarding copper and aluminum cable fusing time-current formulas. There seemed to be a discrepancy in equation 2 as given; consequently, I communicated with Mr. Reeves and found that the equation had been misprinted. The equation should read as follows:

$$S_1 = \frac{2.3\,hH}{I^2\dfrac{r_0H}{y+t_0} - 1} \times \log_{10}\frac{\left(\dfrac{t_f - t_a}{t_0 - t_a}\right)\left(I^2\dfrac{r_0H(y+t_f)}{(y+t_0)(t_f-t_a)} - 1\right)}{I^2\dfrac{r_0H}{t_0 - t_a} - 1} \quad \text{(seconds)} \quad (2)$$

Very truly yours,

F. J. Horacek
Junior Engineer, Consolidated Edison Company of New York, Inc., New York, N. Y.

Tensor Analysis

To the Editor:

In Electrical Engineering for March 1937, page 386, is published a very concise report about the sessions on tensor analysis at the 1937 AIEE winter convention.

Electrical engineers of the whole world, occupied in theoretical work, pay greatest attention and interest to the penetration of tensors into theoretical electrotechnics. This powerful mathematical method meets very contradictary appraisal. For that reason it would be natural to expect that the leader in this problem—United States of America—will publish all the discussion on tensors completely.

Therefore I think I shall express the opinion of all electrical engineers of the whole world, if I shall ask you earnestly to publish completely the report of the discussion on tensors at the winter convention.

Very truly yours,

V. N. Lebedev
Electrical Engineer, Dnepropetrovsk, U.S.S.R.

Personal Items

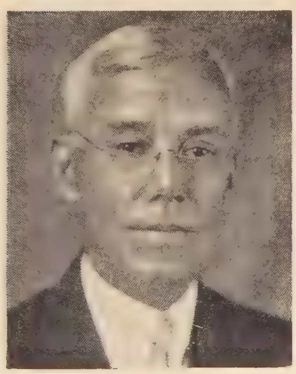
H. B. Dates (A'98, F'32, member for life) professor and head of the department of electrical engineering, Case School of Applied Science, Cleveland, Ohio, has been elected president of the Illuminating Engineering Society. Professor Dates was born July 15, 1869, at New Britain, Conn., and received the degrees of bachelor of science in electrical engineering and electrical engineer (honorary, 1908) at Massachusetts Institute of Technology and Case School of Applied Science, respectively. From 1894 until early in 1896 he worked as a laboratory tester and inspector for the Westinghouse Electric & Manufacturing Company at Newark, N. J., and East Pittsburgh, Pa. In 1896 he received an appointment as professor of physics and electrical engineering at Clarkson School of Technology, where he organized the departments of physics and electrical engineering, planned the curricula, and equipped the laboratories. Professor Dates remained at Clarkson until 1903, when he became professor of electrical engineering and dean of the college of engineering at the University of Colorado. He has been head of the school of electrical engineering at the Case School of Applied Science since 1905, where, in addition to his regular teaching and administrative duties, he has served as a consulting engineer for the Cleveland Board of Education and for several commercial organizations. Professor Dates is a member of the Institute's committee on production and application of light, and was the first chairman (1907–08) of the Cleveland Section. He is a past-vice-president of the Illuminating Engineering Society, a member of the United States National Committee of the International Commission on Illumination, and a member or former member of several committees of that society. Professor Dates is the author of many books and papers on illumination. He is a member of the Society for the Promotion of Engineering Education, Sigma Xi, and Eta Kappa Nu.

F. V. Magalhaes (A'07, F'19) assistant to vice-president, Consolidated Edison Company of New York, Inc., New York, N. Y., has been appointed executive assistant to the president. Mr. Magalhaes was born January 14, 1880, at Sao Paulo, Brazil, and received the degree of electrical engineer at the Polytechnic Institute of Brooklyn (N. Y.) in 1906. Following his graduation he was associated briefly with the Brooklyn Rapid Transit Company and the General Railway Signal Company before entering the meter department of The New York Edison Company in 1907. After 2 years he was made superintendent of the meter department, and in 1917 became superintendent of the test department also. From 1926 to 1928 he was superintendent of distribution and installation, but left the company in 1928 to become vice-president of the Hall Electric Heating Company. That company was liquidated in 1932, at which time Mr. Magalhaes became commercial representative for the General Electric Company at Lynn, Mass. He was appointed assistant to the executive vice-president of The New York Edison Company in 1935, and when the properties of that company and several others were merged recently under the Consolidated Edison Company name, he was retained in a similar capacity in the new organization. Mr. Magalhaes has been a member of the Institute's board of examiners since 1931, having served previously 1923–28, has been Institute representative on the electrical committee of the National Fire Protection Association since 1928, and since 1930 has been representative on the National Fire Waste Council, previously serving for the year 1928–29. He is at present a member of the committee on standards, has served on several other Institute committees, and for some years was secretary and vice-president of the United States National Committee of the International Electrotechnical Commission.

E. A. Harty (A'22, M'36) designing engineer, General Electric Company, Lynn, Mass., has been awarded the AIEE North Eastern District prize for initial paper for his paper "Aging in Copper Oxide Rectifiers." Mr. Harty was born November 13, 1897, at Constantinople, Turkey, and received the degrees of bachelor of science and electrical engineer from Robert College (Turkey) in 1920. Following his graduation he entered the United States Department of State as a clerk in the American Consular Service, but in the following year became a mechanic in the construction department of the Shippley Construction and Supply Company, Brooklyn, N. Y. After serving briefly as an electrician for the New York, New Haven, and Hartford Railroad Company, he entered the student training course of the General Electric Company, Lynn, in 1923. In 1924 Mr. Harty was appointed a research assistant in the Thomson research laboratories of the General Electric Company, and for the ensuing 5 years his work embraced all phases of the design and production of copper-oxide rectifiers. Since 1929 he has been designing engineer on copper-oxide rectifiers, in which capacity he has also been responsible for the maintenance and improvement of the quality of such products. Mr. Harty is the author of several technical articles and papers, including 2 papers presented before the AIEE Lynn Section.

C. W. Leihy (A'30) engineering editor of *Electrical West* and Pacific Coast editor of *Electrical World* has resigned from these positions to take over the editorship of *Electric Light and Power* with headquarters in Chicago, Ill. A native of Portland, Ore. (1905) Mr. Leihy received his education in that state and graduated in electrical engineering from Oregon State College, Corvallis, in 1926. Immediately following graduation, Mr. Leihy became affiliated with the General Electric Company and spent 2 years at Schenectady, N. Y., in the design and commercial departments, after which he was transferred to that company's Seattle, Wash., office as sales engineer. In the fall of 1930 he joined the McGraw-Hill Publishing Company's Pacific Coast organization in San Francisco, Calif. Mr. Leihy has maintained direct contact with electrical-engineering activities throughout the 11 far-western states, and has taken an active part there in AIEE affairs. He is a captain in the United States Field Artillery Reserve.

J. S. Carroll (A'24, M'37) associate professor of electrical engineering, Stanford University, Calif., has received honorable mention in the 1936 AIEE national prize awards for best paper in theory and research


F. V. MAGALHAES


H. B. DATES


E. A. HARTY


C. W. LEIHY

E. M. HUNTER

F. G. BOYCE

A. C. HERWEH

M. F. GILL

for his paper "Laboratory Studies of Conductor Vibration." Doctor Carroll was born November 26, 1891, at Orderville, Utah, and was graduated from the University of Utah with the degree of bachelor of science in electrical engineering in 1920. Following his graduation, he received an appointment to the faculty of the University of Utah as an instructor in electrical engineering, and remained there for 3 years before accepting a similar position at Stanford University in 1924. At that time he enrolled in the graduate engineering school at Stanford, and in the same year received the degree of electrical engineer from that institution; subsequently he undertook further graduate study and received the degree of doctor of philosophy in 1929. He was appointed assistant professor of electrical engineering in 1926, and has been associate professor since 1930. Doctor Carroll has been particularly active in high-voltage research work, having served as director of the Ryan high-voltage laboratory at Stanford, and is the author or co-author of many AIEE papers on that branch of engineering research.

A. C. Herweh (A'37) instructor in electrical engineering, University of Cincinnati (Ohio) has received the 1936 AIEE Middle Eastern District prize for initial paper for his paper "An Open Arc Type of Stroboscope." Mr. Herweh was born January 29, 1907, at Cincinnati, and received the degrees of electrical engineer (1932) and master of science in engineering (1936) at the University of Cincinnati. From 1929 until 1932 he was a design engineer for the Union Gas and Electric Company. After serving for one year (1933–34) as assistant foreman in charge of loudspeaker production of the Crosley Radio Company, Mr. Herweh was designated a teaching fellow in the electrical-engineering department of the University of Cincinnati, and since 1936 has been a full-time instructor in electrical engineering. He is a member of Tau Beta Pi and Eta Kappa Nu.

M. F. Gill (A'14, M'33) formerly co-ordinator for the Pennsylvania Power & Light Company, Allentown, recently was appointed assistant to the president of the Kansas Gas and Electric Company, Wichita. Mr. Gill was born October 4, 1888, at Paris, Texas, and was graduated in electrical engineering at the University of Texas in 1910. Upon graduation he entered the employ of the General Electric Company, Schenectady, N. Y., as a student engineer but returned to Texas in 1913 as resident engineer on construction for the Texas Power and Light Company, Dallas; later he became office engineer and assistant chief engineer, in which position he was in charge of the engineering office of that company. After brief periods of service with the Stone and Webster Engineering Corporation, the United States Army, and the Phoenix Utility Company, he became assistant manager, and later manager, of the Texas Electric Service Company, Breckenridge. In the position of manager Mr. Gill was in responsible charge of all phases of operation, engineering, and construction of the company. In 1928 he was appointed general superintendent of the Phoenix Utility Company at Allentown, Pa., and remained in that capacity until 1935, when he became co-ordinator for the Pennsylvania Power & Light Company.

F. G. Boyce (A'12, M'15) manager of electrical production, transmission, and construction, Consumers Power Co., Jackson, Mich., recently was elected vice-president of the company. Mr. Boyce was born February 8, 1884, at Philadelphia, N. Y., and was graduated from the Bliss Electrical School in 1907, following which he served for 2 years as a lineman before entering the employ of the Allis-Chalmers Manufacturing Company, Milwaukee, Wis., in 1909. He remained with that company until 1913, serving successively as an electrical tester, assistant foreman of the electrical testing department, and erecting engineer. Mr. Boyce then became construction foreman for the Stone and Webster Engineering Corporation and was placed in charge of the construction of several substations along the Mississippi River for the distribution of power from the Keokuk hydroelectric station. On completion of that work he took charge of construction, operation, and maintenance of power plants and substations for the Milwaukee Electric Railway and Light Company. He became affiliated with the Consumers Power Co. in 1917, after a brief association with the Goodyear Tire and Rubber Company at Akron, Ohio. He was made assistant manager of electrical production and transmission at that time, and in 1936 became manager of electrical production, transmission, and construction.

E. M. Hunter (A'28, M'37) central station engineering department, General Electric Company, Schenectady, N. Y., has received the 1936 AIEE North Eastern District prize for best paper for his paper "Tests on Lightning Protection for A-C Rotating Machines." Mr. Hunter was born October 20, 1902, at Portsmouth, N. H., and received the degrees of bachelor of science in electrical engineering (1926) and electrical engineer (1930) at Worcester Polytechnic Institute; in 1931 he received the degree of master of science at Union College. After completing the General Electric test course in 1925, he was transferred to the a-c turbine-generator engineering department, where he was assigned to special design problems and the supervision of factory and field tests. Since 1928 he has been in the central station engineering department, and much of his work has been concerned with system stability studies, especially in relation to design problems. Recently much of his effort has been devoted to a study of the protection of machinery and systems against lightning. He is author or co-author of several AIEE papers on these 2 related fields.

W. E. Mitchell (A'06, F'22) vice-president and general manager of the Georgia Power Company, Atlanta, has been elected a vice-president of the Edison Electric Institute for the term 1937–38. Recently he was also elected president of the Southeastern Electric Exchange. Mr. Mitchell was born June 23, 1882, at Milton, Mass., and received the degree of bachelor of science in electrical engineering at Massachusetts Institute of Technology. Following his graduation he entered the test course of the General Electric Company, Schenectady, N. Y., in 1903, but upon completion of the course in 1905 he went to South America as an assistant electrical engineer for the Sao Paulo (Brazil) Tramway, Light, and Power Company. In 1907 Mr. Mitchell became electrical engineer and operating superintendent of the Bahia Tramway, Light, and Power Company, where he remained until 1911, when he returned to the United States. After a brief period of service with the General Electric Company in San Francisco, Calif., he entered the employ of the Alabama Power Company as an electrical engineer in 1912, and subsequently became operating manager. During the World War Mr. Mitchell was managing director of the Anniston

Steel Company, but returned to the Alabama Power Company in 1918 as assistant general manager and held that position until he was elected president of the Georgia Power Company in 1927.

R. H. CARD (A'22, M'35) engineer for the American Telephone and Telegraph Company, New York, N. Y., has received honorable mention in the 1936 AIEE national prize awards for initial paper for his paper "Earth Resistivity and Geological Structure." Mr. Card was born at Pikeville, Tenn., July 28, 1897, and was graduated from the University of Tennessee with the degree of bachelor of science in electrical engineering in 1919, following which he entered the preliminary training course of the long-lines department of the American Telephone and Telegraph Company. In 1922 he was transferred to the division plant superintendent's office at Philadelphia, Pa., where his duties embraced supervisory work on inductive co-ordination. After 5 years Mr. Card was appointed division engineer in the Philadelphia offices, and was placed in charge of various aspects of transmission engineering, including inductive and structural co-ordination of power and telephone lines within the Philadelphia area. Since 1927 he has been stationed in the office of the long-lines engineer at New York, pursuing investigations of crosstalk and inductive co-ordination for the entire long-lines plant of the company.

E. L. BAILEY (A'19, M'25) electrical engineer for the Chrysler Corporation, Detroit, Mich., has received honorable mention in the 1936 AIEE national prize awards for initial paper for his paper "Induction Heating at Low Temperatures." Mr. Bailey was born January 3, 1885, at Lawrence, Kans., and was graduated from the University of Kansas with a degree in electrical engineering in 1907. Immediately following his graduation he entered the test course of the General Electric Company, Schenectady, N. Y., and upon his completion of the course in 1909 was transferred to the engineering department of the Chicago, Ill., offices of that company. Later he was transferred to the Detroit, Mich., offices of the General Electric Company as district engineer. During the World War he became superintendent of the Gas and Electric Company, Port Huron, Mich., and later a sales engineer for several electrical machinery manufacturers in Detroit. In 1925 he joined the electrical engineering staff of the Fisher Body Division of the General Motors Corporation, and in 1930 became affiliated with the Chrysler Corporation in his present position.

A. H. LAUDER (A'24) motor and generator engineering department, General Electric Company, Schenectady, N. Y., co-author of the paper "Pull-In Characteristics of Synchronous Motors," with S. B. Crary, Jr. (A'31) and D. R. Shoults (A'35) has received honorable mention in the 1936 AIEE national prize awards for best paper in theory and research. Mr. Lauder was born December 27, 1900, at Evanston, Wyo., and received the degree of bachelor of science at the University of Wyoming in 1922. During his senior year he served as an instructor in applied electricity, and following his graduation entered the testing department of the General Electric Company. After completing the test course, Mr. Lauder was transferred to the a-c engineering department, but later was transferred to the motor and generator engineering department, where he has remained continuously. His work in that department consists principally of the design of synchronous machines.

D. R. SHOULTS (A'35) industrial department, General Electric Company, Schenectady, N. Y., co-author of the paper "Pull-In Characteristics of Synchronous Motors," with S. B. Crary, Jr. (A'31) and A. H. Lauder (A'24) has received honorable mention in the 1936 AIEE national prize awards for best paper in theory and research. Mr. Shoults was born June 23, 1903 at Storms, Ohio, and received the degree of bachelor of science in electrical engineering at the University of Idaho in 1925, following which he entered the test course of the General Electric Company. In 1926 he was placed in charge of some of the tests on large motors and generators, and after 3 years was transferred to the industrial department, where his work has been concerned with electrical applications in the paper, lumber, and rubber-mill industries. He is the author of several technical articles.

S. B. CRARY, JR. (A'31) central station engineering department, General Electric Company, Schenectady, N. Y., co-author of the paper "Pull-In Characteristics of Synchronous Machines," with A. H. Lauder (A'24) and D. R. Shoults (A'35) has received honorable mention in the 1936 AIEE national prize awards for best paper in theory and research. Mr. Crary was born May 17, 1905, at Marquette, Mich., and was graduated from Michigan State College with the degree of bachelor of science in electrical engineering in 1927. Upon graduation he entered the test course of the General Electric Company, and has remained in the employ of that company continuously; in 1928 he was transferred to the transformer design department, but served there only briefly before being assigned to the central station engineering department in 1929.

R. D. MAILEY (F'30) vice-president in charge of engineering and manufacture, General Electric Vapor Lamp Company, Hoboken, N. J., recently was awarded an honorary degree of doctor of science by Stevens Institute of Technology as "an electrical engineer and physicist in whose laboratory were developed to their present efficiency as illuminants the mercury-arc lamp, the high-pressure mercury lamp, the sodium lamp, and other notable vapor-lamp equipment . . . . . internationally recognized expert in his field of physical research and industrial development." Mr. Mailey is a member of the Institute's committee on production and application of light.

JACK DELMONTE (A'36) who has been a laboratory technician in the engineer research laboratories of the Firestone Tire and Rubber Company, Akron, Ohio, now is assistant to the chief engineer of development and research, Chicago (Ill.) Flexible Shaft Company. Mr. Delmonte is a native (1913) of New York, N. Y., and an electrical engineering graduate of New York University. He pursued graduate studies in electrical engineering at Massachusetts Institute of Technology and the University of Pennsylvania. Before becoming associated with the Firestone Tire and Rubber Company, he was employed in the Naval Aircraft Factory, United States Navy Yard, Philadelphia, Pa.

E. M. WILLIAMS (Enrolled Student) graduate student in electrical engineering Yale University, New Haven, Conn., with R. F. Huminski, co-author of the paper "Frequency Multipliers," has received honorable mention in the 1936 AIEE national prize awards for Branch paper. Mr. Williams was born February 2, 1915, at New Haven, and received the degree of bachelor of engineering at Yale University in 1936. His present course of study leads to the degree of doctor of engineering. He presented a paper "A High-Voltage Parallel-Plate Electrostatic Voltmeter," at the North Eastern District student convention, Buffalo, N. Y., May 7, 1937.

H. B. FUGE (A'37) assistant engineer, Diehl Manufacturing Company, Elizabethport, N. J., has received honorable mention in the 1936 AIEE national prize award for Branch paper for his paper "A Direct Reading Linear Accelerometer." Mr. Fuge was born December 31, 1915, at Brooklyn, N. Y., and received the degree of bachelor of engineering at the Polytechnic Institute of Brooklyn (N. Y.) in 1936. Immediately after his graduation he entered the employ of the Diehl Manufacturing Company as an assistant in the engineering laboratory. In January 1937 he was promoted to assistant engineer, and has been assigned to fractional-horsepower motor design work.

D. R. BARNEY (Enrolled Student) graduate student in electrical engineering, Massachusetts Institute of Technology, Cambridge, has received honorable mention in the 1936 AIEE national prize awards for Branch paper for his paper "Tidal Power." Mr. Barney is a native (1915) of East Orange, N. J., and an electrical engineering graduate of the Newark College of Engineering. He expects to receive his master's degree in electrical engineering in February 1938.

A. D. FLESHLER (A'34) junior electrical engineer, Transit Commission, New York, N. Y., has been promoted to assistant electrical engineer. Mr. Fleshler is a native (1895) of Bessarabia, Russia, and a graduate of Cooper Union Institute and New York University. Before becoming affiliated with the New York Transit Commission he was employed by the Westinghouse Electric & Manufacturing Company and the Ajax Electric Company.

J. H. TREADWELL (Enrolled Student) Menard, Texas, has received the 1936 AIEE South West District prize for Branch paper for his paper "A Rotating Ball Slip Meter." Mr. Treadwell was born February 22, 1915, at Menard, and is at present enrolled as a student in electrical engineering at The Rice Institute, where he expects to receive the degree of bachelor of science in electrical engineering in 1938.

F. W. SMITH (A'05, M'12) retired president of the Consolidated Edison Company of New York, Inc., New York, N. Y., recently received the honorary degree of doctor of engineering from Stevens Institute of Technology. A brief biographical sketch of Doctor Smith appeared in the June 1937 issue of ELECTRICAL ENGINEERING, page 770, at the time of his retirement.

F. X. LAMB (A'36) chief of the commercial division, engineering department of the Weston Electrical Instrument Corporation, Newark, N. J., recently went to Japan to represent the Weston company as consulting engineer and adviser to the Nippon Electric Company, Tokyo. Mr. Lamb has been associated with the Weston company for more than 15 years.

ASGER VILSTRUP (A'20, M'27) chief electrical engineer, British Columbia Electric Railway Company, Ltd., Vancouver, has been elected chairman of the Northwest Electric Light and Power Association for the term 1937–38. A biographical sketch of Mr. Vilstrup appeared in the February 1937 issue of ELECTRICAL ENGINEERING, page 289.

T. S. TAYLOR (M'21) professor of physics, Washington and Jefferson College, Washington, Pa., recently resigned to become manager of the engineering laboratory and experimental department of the Diehl Manufacturing Company, Elizabethport, N. J. Doctor Taylor formerly was a research physicist for the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

R. C. GIESE (A'19, M'32) division plant engineer, American Telephone and Telegraph Company, Chicago, Ill., has been made district plant superintendent, with offices at Springfield, Ill. Mr. Giese is a native (1893) of Des Moines, Iowa, and attended the State University of Iowa. He has been associated with the American Telephone and Telegraph Company since 1919.

MATTHEW LUCKIESH (A'11, M'15) director of the lighting research laboratory, General Electric Company, Nela Park, Cleveland, Ohio, recently was elected an honorary member of the American Academy of Optometry, in recognition of his contribution to optometric science.

B. H. RULE (A'36) formerly a meter and test engineer, Department of Light and Power of the City of Vernon, Calif., recently was appointed electrical engineer in the astrophysical observatory of California Institute of Technology, Pasadena.

M. V. MAXWELL (M'36) who has been an assistant engineer in the Bureau of Reclamation, Denver, Colo., recently became district engineer in the Detroit, Mich., offices of the Westinghouse Electric & Manufacturing Company.

H. P. BARLOW (A'36) who has been a switchman in the central office of the Associated Telephone Company, Ltd., Ontario, Calif., has been transferred to the Long Beach offices of that company in the capacity of assistant traffic engineer.

M. D. ENGLE (A'21, M'26) superintendent of the station engineering department, Edison Electric Illuminating Company of Boston, Mass., recently was elected a member of the executive committee of the National District Heating Association.

J. T. MOONEY (A'25) has resigned his position with the Lago Oil and Transport Co., Ltd., Aruba, Netherlands West Indies, to become superintendent of the generating plants of the Loup River Power District, Columbus, Nebr.

W. M. SHOBER (A'22) formerly a distribution engineer, Department of Water, Light, and Power, City of Springfield, Ill., now is an electrical installation engineer for the Aluminum Company of America, Alcoa, Tenn.

E. W. HOVER (A'25, M'32) formerly an electrical distribution engineer for the Central Hudson Gas and Electric Corporation Poughkeepsie, N. Y., recently was appointed electrical engineer in the Rural Electrification Administration, Washington, D. C.

ROBERT TRIPLETT (A'32) who has been a junior engineer for the Mackay Radio and Telegraph Company, San Francisco, Calif., now is employed as a receiving engineer at the Point Reyes station of RCA Communications, Inc. Inverness, Calif.

E. C. KELTON (M'26) lieutenant colonel, Engineers Corps, United States Army, who has been stationed at the Army Industrial College, Washington, D. C., as an instructor, has been transferred to Fort McKinley, Philippine Islands.

LIONEL HOECHSTETTER (A'35) has resigned his position as junior engineer with the Westchester Lighting Company, Mount Vernon, N. Y., to become an electrical engineer for the Electricoil Company, New York, N. Y.

J. C. WINSLOW (A'26) electrical engineer for the Westinghouse Electric & Manufacturing Company, Springfield, Mass., has been transferred to the Lima, Ohio, offices of that company.

W. R. WOOD (A'33) has left the employ of the United Fruit Company, New York, N. Y., to become a d-c motor design engineer for the General Electric Company, Lynn, Mass.

GODFREY MORGAN, JR. (M'36) assistant engineer with the Public Service Electric and Gas Company, Camden, N. J., has been transferred to the Princeton, N. J. offices of that company.

E. L. ANGELL (A'34) who has been a clerk in the right of way department of the Narragansett Electric Company, Providence, R. I., has entered the test course of the General Electric Company, Pittsfield, Mass.

H. F. PARK (A'35) formerly chief draftsman for the Fidelity Electric Company, Lancaster, Pa., recently was employed by the Rural Electrification Administration, Washington, D. C.

L. B. LEVESCONTE (A'36) switchgear representative, Westinghouse Electric & Manufacturing Company, Newark, N. J., has been transferred to the Chicago, Ill., offices of that company.

F. C. POAGE (A'25) formerly assistant to the superintendent of power, Idaho Power Company, Boise, has joined the staff of Ebasco Services, Inc., with headquarters at New York, N. Y.

P. W. SEAL (A'33) formerly an engineering assistant, Consolidated Edison Company of New York, Inc., New York, N. Y., now is electrical foreman with the Allegheny Steel Company, Tarentum, Pa.

C. F. WAYER, JR. (A'32) who has been employed by the General Electric Company, Bloomfield, N. J., now is an assistant examiner in the United States Patent Office, Washington, D. C.

B. B. BROWNELL (A'36) formerly employed by the Delco Products Corporation, Dayton, Ohio, now is a junior electrical engineer with the Electro-Motive Corporation, LaGrange, Ill.

K. C. WHITE (A'35) who has been employed by the General Electric Company, Schenectady, N. Y., has been appointed an instructor in electrical engineering at Cornell University, Ithaca, N. Y.

E. H. SCHOENFELD (A'35) formerly employed by Heintz and Kaufman, Ltd., South San Francisco, Calif., now is an engineer for the United Geophysical Company, Pasadena, Calif.

F. J. ELSER (A'32) recently was employed as a radio transmitter tester for the Westinghouse Electric & Manufacturing Company, Chicopee Falls, Mass.

F. B. CONLON (A'31) formerly a sales engineer with the Sheffler Gross Company, Philadelphia, Pa., now is employed by Airtemp, Inc., Dayton, Ohio.

Obituary

GUGLIELMO MARCONI (HM '17, John Fritz Medalist '23) Italian inventor famous for establishing wireless telegraphy on a commercial basis, died quietly of heart paralysis July 20, 1937 at the ancient palace in Rome where he lived and worked. He was born in Italy on April 25, 1874, and was educated privately. Destined by his father to be a musician, Marconi nevertheless turned to science, and by 1895 the idea had become firmly rooted in his mind that a system of telegraphy through space could be provided by means of electromagnetic waves, the existence of which already had been determined by earlier experimenters.

Marconi was the first to devise practical means by which these waves could provide a new method of communication. In 1896 he went to England, taking out during that year the first patent ever granted on wireless telegraphy. An extended series of experiments followed, and his first commercial company was organized in 1897. During the next few years Marconi took out many patents on new devices for wireless telegraphy, and had much to do with the remarkable growth of this new industry in many countries of the world. In December 1901 a prearranged wireless signal was flashed from a station on the coast of Cornwall, England, to another on the rocks of Newfoundland some 2,000 miles away. After several unsuccessful attempts, communication finally was established between these 2 stations. These and other related efforts of Marconi attracted to him the attention of the world during 1901 and 1902. On January 13, 1902, at the annual dinner of the Institute held at the Waldorf-Astoria Hotel, Marconi was the guest of honor in recognition of his contributions to wireless telegraphy. He also was one of the pioneers in the use of short waves for radio communication. During the World War, Marconi served in both the Italian army and navy, and also visited America as a member of the Italian War Commission to the United States Government. He was appointed a delegate to the Peace Conference in Paris in 1919. Among the many honors received by Marconi during his lifetime are the Nobel Prize for Physics in 1909, the Albert Medal of the Royal Society of Arts of Great Britain, and the 1932 Kelvin Medal of the Institution of Civil Engineers of Great Britain. He has been decorated with the Italian order of St. Maurice and St. Lazarus, and with the Grand Cross of the Crown of Italy. In 1915 he was nominated senator of the Kingdom of Italy. In the United States, Marconi has received the Franklin and John Fritz medals and the Medal of Honor of the Institute of Radio Engineers, and other citations. Much of Marconi's time in late years has been spent aboard his yacht "Elettra" on which he had a completely equipped experimental laboratory.

Peter William Sothman (A'07, M'09, F'17) consulting engineer, Mount Tabor, N. J., died June 25, 1937. Mr. Sothman was born May 20, 1870, at Haderslev, Denmark, and was graduated from the Technological Institute of Charlottenburg (Germany) in 1891, with a diploma as electrical and mechanical engineer. Following his graduation, he became construction engineer for Siemens and Halske Company, Berlin, Germany, in which capacity he supervised the construction of several central stations and substations in Germany, South Africa, Russia, and Switzerland. In 1897 he became chief engineer and director of a power plant of Allgemeine Electricitaets Gesellschaft at Strassburg, Germany, and at the same time acted as expert on high-voltage transmission for several German cities. In 1899 Mr. Sothman was appointed technical commissioner for the German government and expert for all the courts in Alsace Lorraine and Baden; concurrently he served as commissioner of law for the Verein Deutscher Electrotechniker and as commissioner and director of the Technological School of Strassburg. He was honored as "ehren doctor Von Academie de Parisienne," in 1905, and in the same year came to the United States and established his own consulting engineering offices at New York, N. Y. In the following year Mr. Sothman was appointed chief engineer of the Hydro-Electric Power Commission of Ontario, in which position he was responsible for the design and construction of several of the Commission's generating plants and transmission lines. He returned to New York in 1912 to establish the consulting engineering firm of the Sothman Corporation, and for the ensuing 25 years continued in that work in the city of New York and its vicinity.

Charles L. Cadle (A'08) president of the New York State Electric and Gas Corporation, Binghamton, N. Y., died July 3, 1937. Mr. Cadle was born March 10, 1879, at Mentor, Ohio, and was graduated from the Case School of Applied Science in the class of 1904, following which he became battery manager for the Cleveland (Ohio) Electric Railway Company. In the following year he became associated with the Electric Railway Improvement Company, Cleveland, and in 1907 was promoted to the position of assistant general manager; however, after only one year in that position he went to Rochester, N. Y., to become electrical engineer for the Rochester Railway Company. Mr. Cadle remained with that company until 1912, when he was appointed to a similar position in the New York State Railways Company, with offices at Rochester. In 1919 he became chief engineer of that company. After serving briefly as superintendent of public works at Albany and pursuing for a time his own consulting engineering business, he became general manager of the Rochester Gas and Electric Company in 1926. In 1932 he was appointed vice-president of the Utilities Management Corporation, New York, N. Y., and in 1935 president of the New York State Electric and Gas Corporation.

Roger S. Taylor (A'17) plant superintendent, Susquehanna Electric Company, Conowingo, Md., died April 27, 1937. Mr. Taylor was born October 7, 1881, at Dukenfield, Cheshire, England, and received his formal education at the Technical School at Ashton-under-Lyne. In 1898 he came to the United States and obtained employment in the motive-power department of the Philadelphia (Pa.) Rapid Transit Company. He remained with that company until he transferred his affiliation to the Philadelphia Suburban Gas and Electric Company in 1912 and was placed in charge of that company's plants at Pottstown and Phoenixville. In 1916 Mr. Taylor joined the operating staff of the Philadelphia Electric Company, later becoming assistant power-plant superintendent and power-plant superintendent, and remained with that company for almost 10 years before becoming associated with the Susquehannah Electric Company as plant superintendent.

Norman McLeod Baxter (A'26) transmission engineer, Ohio Public Service Company, Elyria, died June 24, 1937. Mr. Baxter was born at Halifax, Nova Scotia, June 27, 1883, and attended University Delhousie (Nova Scotia) and the University of Nebraska. In 1905 he became affiliated with the Lincoln (Nebr.) Gas and Electric Light Company as a draftsman, but later was placed in charge of construction and eventually became superintendent of gas and electric distribution before transferring to The Lorain County Electric Company, which later became a part of the Ohio Public Service Company, as general superintendent in 1916. From 1919 to 1922 Mr. Baxter was associated briefly with a public utility company in Connecticut and with the engineering department of The Toledo (Ohio) Edison Company. In 1922 he returned to the employ of the Ohio Edison Company as transmission engineer, and served continuously in that capacity for almost 15 years.

Ralph T. Rossi (A'18, M'34) assistant plant engineer, RCA Communications, Inc., New York, N. Y., died May 28, 1937. Mr. Rossi was born in New York, N. Y., April 27, 1878, and received his formal technical education through private instruction in Europe. From 1904 until 1916 he was associated briefly with several consulting engineering firms and construction companies in New York. In 1916 he became superintendent of distribution for the Public Service Electric and Gas Company, Trenton, N. J., where he remained for 3 years before becoming affiliated with RCA Communications as assistant engineer in charge of construction in 1919. Mr. Rossi was responsible for the construction of many of the transmitting and receiving stations of RCA Communications on every continent except Australia. He was a member of the Institute of Radio Engineers.

Walter Cary (A'07, M'14) vice-president, Westinghouse Electric & Manufacturing Company, New York, N. Y., died July 3, 1937. Mr. Cary was born April 26, 1871, at Milwaukee, Wis., and was graduated from Harvard University in 1893 with the degree of bachelor of arts. In 1894 he entered the employ of the Gibbs Electric Company, Milwaukee, as secretary of the company, but 4 years later became vice-president of the Milwaukee Electric Company. In 1910 he became president of the Milwaukee Electric Company, and in 1904 vice-president and general manager of the Westinghouse Lamp Company, New York, N. Y. He had been vice-president of the Westinghouse Electric & Manufacturing Company since 1918.

William M. O'Brien (A'36) service department, Northwestern Electric Company, Rainier, Ore., was drowned May 2, 1937. Mr. O'Brien was born August 5, 1909, at Portland, Ore., and was graduated from Oregon State College with the degree of bachelor of science in electrical engineering in 1935. He had been associated with the Northwestern Electric Company since his graduation. He was a member of the Society of American Military Engineers.

Membership

Recommended for Transfer

The board of examiners, at its meeting on July 21, 1937, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Bonney, R. B., educational director and employment supervisor, The Mountain States Telephone and Telegraph Company, Denver, Colo.
Pearson, E. F., chief engineer, Northwestern Electric Co., Portland, Ore.
Stevenson, A. R., engineer, General Electric Company, Schenectady, N. Y.
Terry, I. A., assistant engineer, motor and generator engineering department, General Electric Company, Schenectady, N. Y.

4 to Grade of Fellow

To Grade of Member

Arnold, N., assistant professor of engineering drawing, Purdue University, Lafayette, Ind.
Atkinson, F. W., electrical engineer, Owens-Illinois Glass Company, Newark, Ohio.
Brosemer, R. O., assistant engineer, General Electric Company, San Francisco, Calif.
Chapman, F. W., superintendent, Commissioners of Public Works, Greenwood, S. C.
DeWeese, F. C. engineer, Carolina Power and Light Company, Raleigh, N. C.
Eggertson, E. G., assistant electrical engineer, American Gas and Electric Company, New York, N. Y.
Evans, G. T., assistant chief engineer, The Bristol Company, Waterbury, Conn.
Ferri, L. F., protection engineer, The Ohio Public Service Company, Elyria.
Gaston, J. R., manager, industrial transformer division, American Transformer Company, Newark, N. J.
Geer, G. D., superintendent of distribution, Texas Electric Service Company, Sweetwater.
Gehr, G. A., communication engineer, Los Angeles County Department of Forester and Fire Warden, Los Angeles, Calif.
Houston, H. H., electrical engineer, Federal Power Commission, San Francisco, Calif.
Knerr, L. R., assistant engineer, California Railroad Commission, San Francisco.
Lyman, W. J., electrical planning engineer, Duquesne Light Company, Pittsburgh, Pa.
Miner, R. R., electrical engineer, Kansas Gas and Electric Company, Wichita.
Plummer, C. E., chief electrical engineer, Modesto Irrigation District, Modesto, Calif.
Ritter, A. S., planning engineer, Commonwealth Edison Company, Chicago, Ill.
Rogers, T. A., instructor, department of electrical engineering, University of California, Berkeley.
Rogers, T. I., engineer, American Telephone and Telegraph Company, New York, N. Y.
Snyder, W. R., electrical engineer, Manila Electric Company, Manila, P. I.
Wagner, H. H., head design engineer, Pennsylvania Transformer Company, Pittsburgh, Pa.

21 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before August 31, 1937, or October 31, 1937, if the applicant resides outside of the United States or Canada.

Adkins, P. LeR., Mountain States Power Company, Albany, Oregon.
Allard, E. P., Philadelphia Navy Yard, Philadelphia, Pa.
Beisber, M. F., Line Material Co., Memphis, Tenn.
Bloedorn, E., Acro Welder Manufacturing Company, Stegeman Machinery Company, Milwaukee, Wis.
Cramer, J. F., Central Nebraska Power and Irrigation District, Hastings.
Darroch, J. W., Berkeley Steel Construction Company, Berkeley, Calif.
Duffy, E. (Member), New Orleans Public Service, Inc., New Orleans, La.
Eistrat, T., California State Board of Equalization, Sacramento.
Ferrill R. M. (Member), Tennessee Electric Power Company, Chattanooga.
Foreman, W. R., Department of Water & Power, Boulder City, Nevada.
Frakes, J. H., Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.
Goodridge, H. L., 157 Pleasant Street, Malden, Mass.
Grant, V. H., Bureau of Aeronautics, Navy Department, Washington, D. C.
Hero, A. A., General Electric Company, New Orleans, La.
Hildenbrand, C. F., Electric Light and Power Company of Baltimore, Baltimore, Md.
Kelley, J. R., Department of Water and Power, Los Angeles, Calif.
Kirk, D. H., Baton Rouge Electric Company, Baton Rouge, La.
Kobke, W. J., Brooklyn Edison Company, Inc., Brooklyn, N. Y.
Mahannah, W. D., Florida Power and Light Company, Ft. Pierce.
McDougald, A. D., Navy Department, Mare Island, Calif.
McHenry, J. C., Lorain-Medina Rural Electric, Inc. Wellington, Ohio.
McKinley, W. H., 1930 *B* Street, San Diego, Calif.
McReynolds, A. C., Columbia Electric Company, Kennewick, Wash.
Miller, A. N., International Business Machines Corporation, Endicott, N. Y.
Palmer, J. E., Pacific Gas and Electric Company, Fall River Mills, Calif.
Pappas, P. S., Great Lakes Dredge and Dock Company, New York, N. Y.
Parrish, J. L., Tennessee Valley Authority, Norris, Tenn.
Peatfield, R. R., New York and Queens Electric Light and Power Company., Flushing, N.Y.
Phillips, E. J., Jr. (Member), Simmons-Boardman Publishing Corporation, Chicago, Ill.
Preston, J. D. (Member), Florida Power and Light Company, Miami.
Purcell, W. W. R., Alabama Power Company, Birmingham.
Ryan, J. J., Signal Engineering and Manufacturing Company, New York, N. Y.
Santos, E. J., 88 Charlotte St., Detroit, Mich.
Schenck, S. B. (Member), Bessemer and Lake Erie Railroad Company, Greenville, Pa.
Shaffer, E. E., City Hall, San Diego, Calif.
Stanley, H. C., American Gas and Electric Company, New York, N. Y.
Woodward, B. W., International Sound Photos System, San Francisco, Calif.

37 Domestic

Foreign

Bapat, M. N., Tata Hydro Companies, Bombay India.
Epple, R. J., Mene Grande Oil Company, Maracaibo, Venezuela.
Hydari, M., Messrs. Crompton Engineering Company, Ltd., Madras, India.
Kusumoto, S., in care of Hitachi Engineering Works, Sukegawa-cho, Ibaraki-ken, Japan.
Natarajan, K., First Line Beach, Madras, India.

5 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Charlton, H. C., 4827 Wilson Avenue, Montreal Que., Canada.
Evans, Maldwyn F., Canadian Comstock Company, Ltd., Toronto, Ont., Canada.
Gregory, G. A., 1217 Jefferson Street, Olympia, Wash.
Hardy, John E., 1741 Pennsylvania Avenue, Denver, Colo.
Jones, K. B., Trumbull Electric Manufacturing Company, Inc., Ludlow, Ky.
Phillips, Eugene H., 3006½ South Hoover, Los Angeles, Calif.
Phillips, Robert J., 94–26—34th Road, Jackson Heights, N. Y.
Roberts, Fred A., 2010 West Michigan Street, Indianapolis, Ind.
Schaefer, Philip E., 5154 St. Paul Avenue, Chicago, Ill.
Sikofsky, George L., 1206 East New York Avenue, Brooklyn, N. Y.
Stivender, P. M., Allis-Chalmers Manufacturing Company, 135 South La Salle Street, Chicago, Ill.

11 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

GREAT BRITAIN, DEPARTMENT of SCIENTIFIC and INDUSTRIAL RESEARCH. REPORT for 1935–36. London, His Majesty's Stationery Office, 1937. 195 pages, tables, 10x6 inches, paper (obtainable from British Library of Information, 270 Madison Ave., New York, N. Y., $0.95). Affords a summary of the work carried on during the year in the various establishments of the Department.

HOUSE WIRING, by T. W. Poppe and H. P. Strand. New York, Norman W. Henley Publishing Company, 1937. 256 pages, illustrated, 7x4 inches, paper, $1.00. A manual for the wireman, giving directions for planning and installing the wiring in dwellings.

A COURSE in ELECTRICAL ENGINEERING. volume 1. DIRECT CURRENTS. By C. L. Dawes. 3 edition. New York and London, McGraw-Hill Book Company, 1937. 751 pages, illustrated, 8x6 inches, cloth, $4.00. An enlarged edition of a standard textbook on electrical engineering, the first volume of which covers direct currents. Includes fundamental electrical characteristics, magnetism, electrostatics, and d-c machinery.

SOUND WAVES, Their Shape and Speed. By D. C. Miller. New York, Macmillan Company, 1937. 164 pages, illustrated, 9x6 inches, cloth, $2.75. Contains a chapter upon electric-spark photography of sound waves and its application to the study of projectiles in flight and the acoustics of auditoriums.

WAHRSCHEINLICHKEITEN und SCHWANKUNGEN Vorträge von M. Czerny, K. Franz, F. Lubberger, J. Bartels and R. Becker. Edited by F. Lubberger. Berlin, Julius Springer, 1937. 100 pages, illustrated, 10x6 inches, paper, 8.40 rm. A group of 5 treatises on the fundamentals, theory, and application of probabilities and variations.

WAVE MECHANICS, Elementary Theory. By J. Frenkel. 2nd edition. London and New York, Oxford University Press, 1936. 312 pages, illustrated, 10x6 inches, cloth, $6.75. Contains chapters on light, matter, motion of particles or systems of particles, statistical mechanics, application of the quantum statistics to electron theory, and theory of chemical forces.

MITTEILUNGEN aus den FORSCHUNGSANSTALTEN. Bd. 5, Heft 2, February 1937. Berlin, VDI-Verlag. 52 pages, illustrated, 12x8 inches, paper, 3.15 rm. Includes a report on end sleeves for high-tension cables and a description of a new portable mirror galvanometer for spectroscopic analyses of metals.

THOMAS' REGISTER of AMERICAN MANUFACTURERS. 27th edition 1937. New York, Thomas Publishing Company, illustrated, 12x9 inches, cloth, $15. ($10. to former subscribers). Contains classified and indexed lists of manufacturers of all kinds; lists of banks, boards of trade and other commercial organizations, trade papers, leading manufacturers, and trade names.

Industrial Notes

Western Electric Sales.—Sales of the Western Electric Co. totalled $97,355,000 for the first six months of this year as compared with $65,651,000 for the corresponding period last year.

Near-Record Business for G-E.—During the first six months of this year the General Electric Co. received orders amounting to $217,265,619, an increase of 59 per cent over the $136,968,597 received during the same period last year. The record first half year was in 1929 when orders amounted to $220,716,456. Orders during the second quarter of 1937 amounted to $111,518,589, compared with $77,398,718 for the corresponding quarter of 1936, an increase of 44 per cent. The second quarter of this year was the largest, for orders received, since the third quarter of 1929.

General Cable Appointment.—R. S. Hopkins has been appointed by the General Cable Corporation as manager of the New York City sales office, 205 East 42nd St.

Roller-Smith Appointment.—H. R. Kimball, 176 Federal St., Boston, has been appointed by the Roller-Smith Co., New York, as district sales agent for New England.

B-L Electric Appointments.—According to a recent announcement of the B-L Electric Mfg. Co., St. Louis, Mo., producers of rectifiers and condensers, changes in executive personnel have been made as follows: Harold J. Wrape, president; Irvin W. Veigel, treasurer; Carl E. Peters, secretary; R. W. Mansfield, superintendent; Carl H. Massot, purchasing agent.

New Motors.—The Century Electric Co., St. Louis, Mo., announces a new complete line of fractional horsepower motors in sizes from $^1/_6$ to $^3/_4$ hp, repulsion start induction, single phase, split phase, capacitor, polyphase and direct current. This line is designed with interchangeable mounting dimensions for a given horsepower size.

Westinghouse Furnaces to Ford.—The Ford Motor Co. has purchased from the Westinghouse Electric & Mfg. Co., 12 additional bell type furnaces for annealing automobile body stock. Each furnace will be rated at 230 kw with a capacity for annealing two coils 52 inches in diameter, 48 inches in height, giving a total loading of 32,000 pounds per charge. This new installation will give the Ford Motor Co. a total of 38 bell annealing furnaces, 24 of which are of Westinghouse manufacture.

Ground Rods.—Sectional Copperweld ground rods and couplings for deep, low-resistance grounds are a new development, announced by the Copperweld Steel Co., Glassport, Pa. Cold-drawn for rigidity, the Copperweld sections are threaded on both ends and joined as they are driven by means of a threaded bronze coupling. It is claimed that sectional Copperweld rods may easily be driven to depths of 40 or 50 feet.

Porcelain Case Capacitors.—A line of porcelain case, high voltage, mica capacitors is announced by Aerovox Corporation, 70 Washington St., Brooklyn, N. Y., for use in radio transmitters and for other electronic purposes. Each unit is housed in a glazed porcelain case and is provided with heavy brass terminal studs and lock nuts. Capacities range from .00005 to .1 mfd. as well as d-c test voltages from 2000 to 12,500.

Reversing Motor Starter.—Allis-Chalmers Mfg. Co., Condit Works, Boston, has announced a new reversing motor starter designated type AP-7-R, furnished for $7^1/_2$ hp, 550 volts or less. The starter consists of two type AP-7 motor starter units, mechanically interlocked so that either unit cannot be closed if the other is closed. The starter units are equipped with Ruptors—enclosing chambers which confine and depotentiate the arc formed by circuit interruption. Other features include large, silver, double-break contacts; solenoid operated, vertical make and break; unit construction, pole units consisting of individual molded bases mounted on a steel chassis, and enclosed temperature overload relays, affording positive motor protection; undervoltage protection inherently provided.

Trade Literature

Switches.—Bulletin 54, 8 pp. Describes group operated air switches, tilting insulator type. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Calif.

Circuit Breakers.—Bulletin GEA-2406A, 4 pp. Describes type FKO outdoor oil-blast circuit breakers; 7500 volts, 400 and 600 amperes, 50,000 kva, 2 or 3 poles, framework or pole mounted. General Electric Co., Schenectady, N. Y.

Bakelite.—Bulletin, 16 pp., "The Versatile Service of Bakelite Materials." Describes the development of Bakelite resinous materials, their general characteristics, properties and applications. Bakelite Corp., 247 Park Ave., New York City.

Testing Equipment.—Bulletin, 8 pp. Describes R-F signal generators, R-F oscillators, service laboratories, oscillographs, power supplies, vacuum-tube voltmeters, etc. The Clough-Brengle Co., 2815 W. 19th St., Chicago, Ill.

Rectifier Tubes.—Bulletin, 44 pp. Describes various types of gaseous discharge rectifier and control rectifier tubes. Characteristics and applications are presented at length. Prices are listed. Electrons, Inc., 127 Sussex Ave., Newark, N. J.

Splices and Tapes.—A new and revised edition of this book, which includes such chapters as the importance of a perfect splice, requirements for a splicing compound, for adhesive tape, and instructions for joining, The Okonite Co., Passaic, N. J.

Switchgear.—Bulletin GEA 2605, 18 pp., "Modern Switchgear." Summarizes 137 separate products from the complete line of G-E switchgear and contains publication numbers of descriptive bulletins giving additional information. General Electric Co., Schenectady, N. Y.

Rubber Substitute.—Bulletin 16 pp. Describes Neoprene, an engineering material with rubber-like properties which resists the deteriorating effects of oil, heat, sunlight, chemicals and oxidation. Among its applications is that of insulating electrical cables. E. I. du Pont de Nemours & Co., Wilmington, Del.

Neon Transformer.—Bulletin 143. Describes a neon transformer, the Acme "Autopak," to illuminate neon signs and displays installed in automobiles. No special equipment or extra generator is necessary as current is supplied from the regular automobile generator. The Acme Elec. & Mfg. Co., 1446 Hamilton Ave., Cleveland, O.

Temperature Instruments.—Catalog 1060C, 56 pp. Describes indicating and recording temperature and pressure instruments. Much of the data on the latest developments in these instruments has not heretofore been published. Numerous illustrations show the manner of operation and how the instruments are serving the process industries. C. J. Tagliabue Mfg. Co., Park & Nostrand Aves., Brooklyn, N. Y.

Cables.—Bulletin C-27, 20 pp. Describes Anaconda Duraseal cable, a non-metallic sheathed cable for direct burial in the ground. In addition to complete descriptions of the types available and their uses, helpful information relative to application, installation and other engineering data are included. Anaconda Wire & Cable Co., 25 Broadway, New York City.

Motors.—Catalog 60 pp. Describes construction features, advantages and applications of practically every commercial type of motor. Included are engineering data on various types of special motor applications and construction. A detailed analysis is presented on the characteristics of squirrel-cage motors, motors for centrifugals, etc. The Louis Allis Co., Milwaukee, Wis.

Insulation Test Set.—Catalog E-54(1), 4 pp. Describes a new insulation resistance test set, using a guarded circuit, entirely free from the effects of leakage currents. Switches are designed to simplify operation and eliminate calculation. Calibration of the galvanometer deflections is facilitated by the specially designed Ayrton shunt. Simply turning the shunt to the calibrating portion automatically connects the circuit for calibration. Results are obtained by merely dividing the calibration reading by the test reading. The instrument conforms with the ASTM "Standard Methods of Test for D-C Resistance of Insulating Materials." Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.